CLIMATE CHANGE: ARE GREENHOUSE GAS EMISSIONS FROM HUMAN ACTIVITIES CONTRIBUTING TO THE WARMING OF THE PLANET?

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY AND AIR QUALITY

OF THE

COMMITTEE ON ENERGY AND COMMERCE

HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

FIRST SESSION

MARCH 7, 2007

Serial No. 110–14

Printed for the use of the Committee on Energy and Commerce

energycommerce.house.gov

U.S. GOVERNMENT PRINTING OFFICE

37–414 PDF WASHINGTON : 2007

For sale by the Superintendent of Documents, U.S. Government Printing Office
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CLIMATE CHANGE: ARE GREENHOUSE GAS EMISSIONS FROM HUMAN ACTIVITIES CONTRIBUTING TO THE WARMING OF THE PLANET?

WEDNESDAY, MARCH 7, 2007

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY AND AIR QUALITY,
COMMITTEE ON ENERGY AND COMMERCE,
Washington, DC.

The subcommittee met, pursuant to call, at 10:00 a.m., in room 2322 of the Rayburn House Office Building, Hon. Rick Boucher (chairman) presiding.

Members present: Representatives Butterfield, Melancon, Barrow, Waxman, Markey, Inslee, Baldwin, Ross, Hooley, Dingell, Hastert, Upton, Whitfield, Shimkus, Buyer, Walden, Sullivan, Burgess and Barton.

Staff present: Sue Sheridan, Laura Vaught, Bruce Harris, Lorie Schmidt, Chris Treanor, David McCarthy, Kurt Bilas, and Peter Kielty.

OPENING STATEMENT OF HON. RICK BOUCHER, A REPRESENTATIVE IN CONGRESS FROM THE COMMONWEALTH OF VIRGINIA

Mr. BOUCHER. The subcommittee will come to order.

Today we examine the scientific evidence regarding global temperature changes and their relationship to human activity. At a later date the subcommittee will examine scientific opinion on the effects of temperature changes on weather patterns, ocean levels and habitat.

The scientists on our panel today are all noted experts in their field and we welcome them to the subcommittee this morning. Their presentations will address the questions of whether global temperatures are increasing and to what extent any changes in temperatures are a consequence of human activity rather than natural climate variability and how future temperatures may be affected by current and future human activity. Over the past several decades, a vigorous debate has occurred over whether global temperatures are rising and whether any increases are being caused by human activity. The scientific opinion now appears to be solidifying with widespread agreement that temperatures are rising and that human activity is the principle cause. The recently released Intergovernmental Panel on Climate Change report reflects that consensus. It concludes with more than 90 percent certainty that temperatures are rising and that human contributions are causing most of the observed increases. This conclusion stands in sharp contrast with the panel report of several years ago reaching the same conclusions but only with a certainty of 66 percent.

Today's witnesses will comment on the IPCC report and on relevant research findings and conclusions which can be drawn from those research findings. I appreciate the attendance this morning of our expert witnesses and I very much look forward to hearing from them.

We have at about 11:00 this morning a joint meeting between the House of Representatives and the Senate for the purpose of hearing from a visiting head of state, and under the rules of the House, we will not be able to continue the subcommittee hearing during the pendency of that joint meeting between the House and the Senate and so Mr. Hastert and I have agreed that what we will do is, go as far as we can in this hearing, recess during the pendency of the joint hearing between the House and Senate and then come back to finish this hearing at such point as that joint meeting of the House and Senate has been concluded.

With those comments, I am pleased now to recognize the ranking member of this subcommittee, the gentleman from Illinois, Mr. Hastert, for 5 minutes.

OPENING STATEMENT OF HON. J. DENNIS HASTERT, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF ILLINOIS

Mr. HASTERT. Thank you, Chairman Boucher.

This morning we begin the science of global warming. Today's hearing is actually the beginning, in my view, of a thorough examination we must perform before moving forward with legislation proposing far-reaching economic implications. In fact, Mr. Chairman, I know you wanted to hold this hearing earlier in the process but you were forced to reschedule due to last month's severe winter storms, an irony lost on few. We just couldn't get the witnesses here.

The question before us concerns the nature, extent and rate of global warming that has been observed and how human emissions of greenhouse gases figure into these observations. As we dig into the questions of man's contribution to global warming, I believe it is essential that we develop a broader perspective on what we know about climate effects, both natural and manmade.

Many climate scientists acknowledge the deep complexity and limits of human knowledge of the climate system. This contrasts with the overly simplistic reporting of global warming and the climate change risks that we see in the mass media, whose treatment of the subject is often superficial and sensational. For policymakers, that is a dangerous combination.

Mr. Chairman, we must avoid falling prey to the sensational. We must not miss out on the important questions or the practical opportunities that can help us address the challenges of global warming in an economically prudent fashion.

In 2001, the National Research Council released its reported entitled "Climate Change Science and Analysis of Some Key Questions." The NRC made an important observation in their report, and here is a direct quote: "The most valuable contribution U.S.

scientists can make is to continually question basic assumptions and conclusions, promote clear and careful appraisal and presentation of the uncertainties about climate change as well as those areas in which science is leading robust conclusion."

We should heed the advice of our top scientists. We need to keep asking, are we focused on the right science questions, are we focused on the right policy issues. For example, should we be concerned with just our own unilateral steps to reverse climate trends or should we address the effect of climate change more broadly as it relates to regions and local areas regardless of the temperature? How should we understand human influence in this broader context of the climate?

I am hopeful the witnesses today can shed some light on these questions, that they can help us determine if we are looking at the issue properly. I am particularly interested in hearing whether we have a good handle on the relative contribution of greenhouse emissions to climate change compared with other human and natural resources. I would like to learn about the limits of our ability to attribute greenhouse gas emissions to global warming and what is needed to improve that ability. I would like to learn more about where the latest research is leading and how that might be changing the assumptions scientists have had about the issue.

Last month the United States Intergovernmental Panel on Climate Change said, in effect, global warming is unequivocal; details to follow. I happen to believe, however, that saying global warming is unequivocal doesn't end the discussion; it begins it. How exactly do man's labors and industry connect to that warning? Is that connection the most relevant issue for us to address? Can we effectively change climate, address climate without forsaking our ability to deal with the other challenges of nature and human development that will confront us? We have to adapt to climate change no matter what is the cause, it is the way it has been forever, and energy policy plays an important role in that ability to address it. Energy animates our economic vitality. It is that vitality that gives us the ability to meet the challenges that nature delivers upon us.

Let me thank the distinguished scientists before us today who have taken time from their busy schedule to attend the hearing. I look forward to your insights in these matters and I thank you, Mr. Chairman.

Mr. BOUCHER. Thank you very much, Mr. Hastert.

The gentleman from Michigan, the chairman of the full committee, Mr. Dingell, is recognized for 5 minutes.

OPENING STATEMENT OF HON. JOHN D. DINGELL, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF MICHIGAN

Mr. DINGELL. Mr. Chairman, thank you for your kindness and thank you for calling a very worthwhile series of hearings on climate change. It will be most helpful as we go forward to the consideration of this legislation.

Now, I would like to also thank our panel. Ladies and gentlemen, thank you for being here and thank you for your time and for your assistance to the committee.

Today we will examine the scientific question of whether greenhouse gas emissions from human activities are contributing and will continue to contribute to a warming of this planet. While many of us have had significant doubts about the question in the past, today it seems to us that science on the question has been settled.

The extent of scientific consensus on this matter is well reflected by the recently published findings of the Intergovernmental Panel on Climate Change, IPCC, which was just released and entitled "Summary for Policymakers" for its fourth assessment report. The report was produced by some 600 authors from 40 countries, over 620 expert reviewers and a large number of government reviewers also participated. Representatives from 113 governments, including the United States, reviewed and revised the summary line by line before adopting it and accepting the underlying report.

The IPCC found that the warming of the climate system is unequivocal and that most of the observed increase in globally average temperatures since the mid–20th century is very likely due to the observed increase in anthropogenic greenhouse gas emissions. By "very likely" the IPCC means a nine in 10 chance. For the future, the IPCC found that changes in the global climate system in the 21st century would very likely be larger than those observed in the 20th century. Indeed, even the administration seems to be in agreement with this point. Right after the IPCC report was released, Secretary of Energy Samuel Bodman was reported as saying, "We are very pleased with it. We are embracing it. We agree with it." He went on to add that "human activity is contributing to the changes in our Earth's climate and that issue is no longer up for debate."

Last month I had a fascinating discussion with some of the scientists responsible for the IPCC report. I asked detailed questions, some technical and some challenging. The answers I received were forthright. They explained that they had looked at changes in solar radiation, volcanic eruptions, urban heat islands and many other phenomena that are contributing to climate change. They explained that some of these factors are important for local temperature but that the only explanation for the large increase in global temperatures are the greenhouse gases which we are adding to the atmosphere. The scientists explained that there are some areas where scientific uncertainty exists. On the central question of man's contribution to the increase of global temperature due to greenhouse gas emissions, however, the issue is clear.

It is important for the committee to probe renowned scientists to better understand what the science is telling us and how we are to answer the questions that are now before us. We need to find out where the science gives us clear answers and where the science gives us fuzzy answers. Today we are focusing on the threshold question of the extent to which greenhouse gas emissions from human activities are causing an increase in global temperature. At a future hearing we will explore the consequences of global warming for the Earth's systems. In other words, we will be asking why it matters that we are increasing global temperatures.

In closing, Mr. Chairman, I hope that the members will use this opportunity to ask tough questions and to seek answers for any uncertainty they may have about the science of climate change.

I thank you again for the hearings, and I thank also again our panel for their assistance to us.

I yield back the balance of my time.

Mr. BOUCHER. Thank you, Mr. Dingell.

Mr. Shimkus for 5 minutes.

OPENING STATEMENT OF HON. JOHN SHIMKUS, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF ILLINOIS

Mr. SHIMKUS. Thank you, Mr. Chairman, and at the risk of trying to be as funny as my friend Mr. Markey, who I had great discussions with yesterday and then after the hearing, I was hesitant to say this, Ed, but we had hearings like this over many years and it was always in July, and if I heard Ed say it once, I heard him say it a hundred times: it is ironic that we are having a global warming hearing on the hottest day, in the hottest month, in the hottest year and the hottest century. It is snowing on March 7 and I would venture to say that it has been a pretty the cold February and March than what we have been used to in the last couple years. So for levity's sake, I throw that out, Ed, and Ed and I are going to have a good fun time in the next couple years in this whole debate.

I want to draw attention also to the February 5 Wall Street Journal editorial and I think this sums up kind of where a lot of us are: "The IPCC report should be understood as one more contribution to the warming debate, not some definitive last word that justifies radical policy change. It can be hard to keep one's head when everyone else is predicting the apocalypse but that is all the more reason to keep cool and focused on actual science," and that is why you are here today. We hope to ask and hear from you noted scientists.

Most of us aren't that knowledgeable in the science. We are laymen who will try to move the country into good policy direction. There are always unintended consequences of legislative action which could be devastating and so we have to try to find balance. We want this to be a deliberative process. I think the committee is taking it in all the seriousness that is intended. We want to make sure we understand the reliability of knowledge and do our job in making sure we are gathering all the evidence from all the factors. This is our second hearing of this committee and we have many more to go. We appreciate your attendance. I look forward to hearing your testimony.

Mr. Chairman, I yield back my time.

Mr. BOUCHER. Thank you very much, Mr. Shimkus.

Mr. Waxman from California for 3 minutes.

Mr. WAXMAN. Thank you, Mr. Chairman. I am going to forego an opening statement in exchange for a lengthier time to question the witnesses.

Mr. BOUCHER. Thank you, Mr. Waxman, and I would note that any member who desires to waive his opening statement will have 3 minutes added to his questioning time for the panel of witnesses.

The gentleman from Massachusetts, Mr. Markey, for 3 minutes.

Mr. MARKEY. I pass.

Mr. BOUCHER. Mr. Markey waives.

For 3 minutes, the gentleman from Washington, Mr. Inslee, is recognized.

Mr. INSLEE. I will pass.

Mr. BOUCHER. Mr. Inslee passes.

Mr. Barrow from Georgia.

Mr. BARROW. I will pass.

Mr. BOUCHER. Mr. Barrow also passes.

The gentlewoman from Wisconsin, Ms. Baldwin, for 3 minutes.

OPENING STATEMENT OF HON. TAMMY BALDWIN, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF WISCONSIN

Ms. BALDWIN. Thank you, Mr. Chairman.

I want to express my gratefulness for this opportunity in this hearing today because for years undue political considerations have really kept us from reaching this point. Naysayers ignored clear warnings that human activity was creating significant changes in regional and global climate. They dismissed calls for action, claiming that alarmists were simply trying to focus attention on everything green. But the tides have turned and those of us who long ago committed ourselves to focusing on global changes in climate now have the backing of the congressional leadership and the international community in calling for action.

The IPCC report is of vast importance. Not only does it confirm that climate change is real but it also confirms that human activities are the main cause. This report is not the work of politicians nor the work of zealots. Rather, it is a consensus of the scientific community of representatives from more than 113 countries of nearly 600 authors. These are the experts who have been to the top of the mountains, the bottom of the oceans, across deserts and icy fields, crisscrossing our planet to analyze the Earth's changing climate. In reaching their conclusions, they have surveyed climate data, observed geographic conditions and evaluated severe weather trends. These scientists have clearly done their work uninfluenced by politics or personal agenda and now it is time for us to do ours.

We must take the knowledge and the data that has been presented to us and create sound policy that will result in a reduction of our greenhouse gas emissions. It won't be easy. We have questions to answer. For instance, what role will renewable energy play in our future and how can we begin to conserve energy now through efficient changes in the way we power our homes, operate our appliances or run our vehicles. While there are challenges ahead, our Nation, our businesses, our communities are in the best position to reshape our future. We understand the consequences of inaction and we are prepared to take steps necessary to preserve our planet for future generations. As stewards, protecting our environment has been our responsibility and now we are making it a priority.

I look forward to hearing from our experts here today about how they reached their conclusions about their recommendations and for how we can reverse course and reduce our greenhouse gases, ensuring a healthy planet for generations to come.

Thank you, Mr. Chairman, again. I yield back the balance of my time.

Mr. BOUCHER. Thank you, Ms. Baldwin.
Mr. Buyer for 3 minutes.
Mr. BUYER. I pass.
Mr. BOUCHER. Mr. Buyer passes.
Mr. Upton for 3 minutes.
Mr. UPTON. I pass.
Mr. BOUCHER. Mr. Upton passes.
Mr. Burgess for 3 minutes.

OPENING STATEMENT OF HON. MICHAEL C. BURGESS, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF TEXAS

Mr. BURGESS. Thank you, Mr. Chairman, and I too want to thank you for convening this hearing. I think these hearings have been extremely informative and this morning's science hearing is essential to what we are doing here on the legislative process so I am glad we were able to reschedule this hearing, canceled last month due to an ice storm and put in jeopardy by a snowstorm but it is a timely hearing nevertheless.

I am really kind of puzzled why this wasn't actually our first hearing. Instead of starting from the beginning with the science, we started with the solutions, cap and trade proposals and carbon sequestration, but now that we have finally gotten around to it, this is critical for part of our discussion.

If I could, I think have one slide to put up on the screen in the brief time allotted to me, and that is not it. Well, we will get this handed out. But according to EPA data, water vapor accounts for 95 percent of greenhouse gases. There it is.

[Slide shown.]

Ocean biologic activity, volcanoes, decaying plants are an additional 4.72 percent and the last small sliver is the human contribution, less than one-third of 1 percent. But today we are going to focus like a laser beam on that less than one-third of 1 percent but I think it is important that we don't forget the context in which we are working. The human additions to the greenhouse gas emissions come from multiple sources including livestock, land use changes, fire suppression systems, electricity plants and tailpipes. I believe that Dr. Avissar from Duke University will be focusing his testimony on this broader context.

I realize that this is a topic that will be addressed in a future hearing by the subcommittee but I think it is important that as we begin to examine the causes of global climate change, we not forget the economic consequences of policy decisions made by this body as we look at this legislation.

Regardless of the reason, whether you are a fan of global warming, of peak oil or just feel it is a cause for a national security concern, removing some carbon from the economic equation is an idea that has merit, but at the same time, we must not sacrifice our economy as we make that transition, because after all, it is the health of our economy that will allow us to make that transition, and I think that is an important point to keep in mind but also I would just share this concern: Global warming and climate change are not interchangeable terms. They are not synonymous and we are going to hear more in this hearing about the differences from some of today's witnesses, and I believe Dr. Christy is going to be talking about as we discussed some in our oversight hearing last year.

Thank you, Mr. Chairman, and I will yield back my remaining 12 seconds.

Mr. BOUCHER. Thank you very much, Mr. Burgess.

Mr. Shadegg from Arizona is recognized for 3 minutes.

Mr. SHADEGG. Mr. Chairman, I will pass other than to commend you for holding this hearing. I think it is important that we look at the science, both the science as to the cause of whatever warming is occurring and the science as to how we can deal with it, and I commend you.

Mr. BOUCHER. Thank you very much, Mr. Shadegg.

That concludes the time for opening statements. Statements for the record will be accepted at this time.

[The prepared statement of Mr. Barton follows:]

PREPARED STATEMENT OF HON. JOE BARTON, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF TEXAS

Thank you, Chairman Boucher, for this initial hearing on the question of man's contribution to global warming.

I commend you and Chairman Dingell for putting together a series of hearings on global warming science and policy. Our committee's tradition of open process has historically enabled us to take on the tough economic and public health issues despite our geographic, ideological, and political diversity.

We are addressing global warming, but we're not doing it in a vacuum. We're also charged with make sure that people in America have the energy that powers our jobs and, through them, our people's opportunity to succeed. If we do our jobs, people will keep their jobs.

I hope today's hearing and the ones that follow will help each of us reach rational conclusions, based on real evidence, about the reliability of our knowledge that CO^2 has the sort of impact on planetary temperature as people say.

It's important to recognize that this is not about the weather on any given day. When we met to examine the dubious statistical validity of some global warming forecasts last summer, it was very hot. I think we picked one of the hottest days of the year. Today the weather is uncharacteristically cold. I'm sure some would prefer to wait until the weather matches the theory, but this is serious business and I hope we can each concede that any day's weather has nothing to do with the issue.

There has been significant scientific debate about this issue, including discussion before this committee. In last summer's hearings, we asked about the historical temperature records and other climate observations. We asked whether the most politically influential modeling conclusions were adequately supported by those observations.

I said then that I accept that the science on this matter is uneven, uncertain, and evolving. That certainly hasn't changed, but now we seem to be pressuring ourselves, or someone is pressuring us, to legislate first and get the facts later. I hope we won't do that. I want to make sure we get the best information available so we have a full and accurate definition of the problem before we start making decisions that will be among the toughest of our careers.

The key question we face is how our decisions affect the lives of the people who send us here. They expect us to make decisions, and they do not expect us to make wrong ones.

I will follow the guidance of my friend, Chairman Dingell: "First, do no harm."

We have to be clear about the issues before us. Discussion of capping CO^2 often misses an essential fact. Carbon dioxide, unlike carbon monoxide and other compounds ending in "oxide," is not toxic. It is not a pollutant. It is not only natural, it is indispensable for life on this planet.

What we need to understand is:

1. How does CO^2 fit into the atmospheric mix? I'm told all CO^2 is only 0.038 percent of atmospheric gases;
2. How does the CO^2 from fossil fuel combustion fit into the total annual CO^2 increase in the atmosphere? I'm told it's only 0.4 percent of this amount.
3. How does U.S. fossil fuel consumption fit into mankind's overall share of fossil energy use? I'm told it's 22 percent and shrinking; That means if we shut down 100

percent of all fossil fuel use in the United States, we would only reduce CO^2 growth in the atmosphere by 0.088 percent. That's 0.0003 percent of the atmospheric gases, and China will be filling in the gap, and then some.

4. How much will any legislation we consider actually change the total U.S. emissions and, in turn, change total human emissions and, in turn, effect global greenhouse gas concentrations?

In that real world context, we must ask: what legislation, if any, can we enact this year that will plainly and significantly improve the health and lives of people around the world a hundred years from now?

What will it cost? The people who will pay for our policy decisions are taxpayers and consumers and workers. What amount is the right amount to take from them and their families for our policies?

We also have to weigh what the opportunity cost might be in terms of other global problems we neglect because of our huge economic and political investment in this issue.

And we need to understand whether well-meaning steps to cap CO^2 here and now will simply drive industry offshore where control of actual pollution such as SOx, NOx, mercury, and particulate is far more lax.

Whether we like it or not, CO^2 correlates to national economic activity. That means jobs, and the ability of working families to thrive is defined by jobs. Despite impressive gains in energy intensity over the past few years, a basic reality is that with the technology mix deployed today, to cap CO^2 emissions restrains economic output, jeopardizes economic growth, and eliminates people's jobs.

Now there are three camps in the political discussion about capping CO^2. One camp doesn't care. Its members are either indifferent or hostile to economic growth. Some of them see the de-industrialization of the U.S. and they welcome it.

The opposite camp strongly favors economic growth and opportunity for America, as well as for people around the world, and worries that this Congress could put domestic growth and opportunity at risk.

The middle camp, however, is the most troubling. They're the ones who want so badly to believe we can easily and inexpensively innovate our way out of the linkage between CO^2 and economic vitality that they are willing to say, "Cap now, details to follow."

That's why we must study the science, the policy proposals, the costs, and the benefits, and assess them all carefully. That is the path you, Chairman Boucher and Chairman Dingell, have outlined for us.

I welcome our witnesses. Your views are critical for us to understand what the state of science is. Please be clear with us, and don't hesitate to separate the certainties from the uncertainties.

Thank you, Mr. Chairman.

Mr. BOUCHER.We are now pleased to welcome our panel of witnesses. I will say a brief word of introduction about each of them.

Dr. James Hurrell joins us from the National Center for Atmospheric Research in Boulder, CO, where he is a senior scientist and the director of the Climate and Global Dynamics Division. He was a contributing author to both the third and fourth assessment reports of the Intergovernmental Panel on Climate Change. He was a lead author on the U.S. climate change science program's synthesis and assessment product on temperature changes in the lower atmosphere and he is currently serving on a National Research Council committee that is tasked to provide strategic advice.

Dr. Gabriele Hegerl joins us from Duke University where she is a research professor at the Nicholas School of the Environmental and Earth Sciences. She was a lead author in the IPCC's third assessment report. For the fourth assessment report, she was a coordinating lead author for the chapter that focuses on determining the causes of observed climate changes.

Dr. Michael Oppenheimer joins us from Princeton University where he is the Albert G. Milbank professor of geosciences and international affairs. He is affiliated with the Department of Geosciences, the Woodrow Wilson School of Public and International Affairs and the Princeton Environmental Institute. He was a lead or contributing author to various chapters of the IPCC's third assessment report and is a lead and contributing author to the fourth assessment report.

Dr. Roni Avissar also joins us from Duke University where he is the W.H. Gardner professor and chair of the Department of Civil and Environmental Engineering. His research is focused on development and evaluation of various environmental fluid dynamics models to study ocean, land, atmospheric interactions at the various spatial and temporal scales.

Dr. John Christy joins us from the University of Alabama in Huntsville where he is a professor and director of the Earth Systems Science Center. He is also Alabama's State climatologist. He was a lead author of the IPCC's third assessment report and is a contributor to the fourth assessment report.

We welcome each of our witnesses. Your prepared written statements will be made a part of the record and we would be pleased to receive your oral summaries of approximately 5 minutes.

Dr. Hurrell, we will be pleased to begin with you.

STATEMENT OF JAMES W. HURRELL, DIRECTOR, CLIMATE AND GLOBAL DYNAMICS DIVISION, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Mr. HURRELL. Mr. Chairman, I thank you, Ranking Member Hastert and the other members of the subcommittee for the opportunity to speak with you today on observed and likely future changes in climate and the contribution from human activity to those changes.

Although uncertainties continue to exist, significant advances in the scientific understanding of climate change now make it clear, as recently stated by the IPCC, that the warming of the climate system is unequivocal and that this warming goes beyond the range of natural variability.

The globe is warming dramatically compared with natural historical rates of change. Global surface temperatures today are more than 1.4 degrees Fahrenheit warmer than at the beginning of the 20th century and rates of temperature rise are greatest in recent decades. Eleven of the last 12 years rank among the 12 warmest since 1850 and four of the warmest 5 years on record have occurred since 2001. This past year, 2006, was the warmest on record over the United States. There is a very high degree of confidence in these numbers. Urban heat island effects, for instance, are real but very local and they have been accounted for in the analyses. There is no urban heat island effect over the oceans where the warming has been very pronounced at both the surface and at depth. Moreover the ocean warming causes seawater to expand and thus contributes to global sea level rise of more than 1.3 inches since 1993 and 6.7 inches over the last century.

A key point is that an increasing number of many independent observations give a consistent picture of a warming world. There has been a widespread reduction in frost. There have been more warm extremes and decreases are occurring in snow cover, Arctic sea ice extent and thickness, and mountain glacier mass and extent. Increases in atmospheric water vapor content and resulting heavier precipitation events, increased drought and increasing atmospheric temperatures above the surface are other signals of a warming world.

Today's best climate models are now able to reproduce these major climate changes of the past century. Climate models are not perfect and some models are better than others. Uncertainties arise from shortcomings in our understanding of climate processes and how best to represent them. Other forcings need to be more fully considered such as historical and likely future changes in land use. Yet in spite of these uncertainties, giving good replication to the past, climate models are extremely useful tools for understanding and determining the changes in forcing that are driving the observed warming.

Forcings imposed on the climate system can be natural in origin such as changes in solar luminosity or volcanic eruptions or human-induced such as the buildup of greenhouse gas concentrations in the atmosphere. These concentrations have increased markedly as the result of human activities and they are now higher than at any time in at least the last 650,000 years.

Climate model simulations that account for such changes in climate forcings have now shown that surface warming of recent decades is mainly a response to the increased concentrations of greenhouse gases and sulfate aerosols in the atmosphere. When the models are run without these forcing changes, the remaining natural forcings and intrinsic natural variability fail to capture the almost linear increase in global surface temperature over the past 25 years.

Moreover, observed increases in continental and ocean basin scale temperatures as well as observed changes in precipitation and other measures such as climate extremes are only stimulated by models that include anthropogenic forcings. These simulations have therefore convincingly shown that climate is changing in ways that cannot be accounted for by natural variability or by changes in natural forcings such as changes in the sun. Moreover this attribution of the recent climate change has direct implications for the future. Because of the very long lifetime of carbon dioxide in the atmosphere and the slow equilibration of the oceans, there is a substantial future commitment to further global climate change even if concentrations of greenhouse gases in the atmosphere remain at current levels.

In summary, the scientific understanding of climate change is now sufficiently clear to show that climate change from global warming is already upon us. Uncertainties do remain, especially regarding how climate will change at regional and local scales, but the climate is changing and the rate of change as projected exceeds anything seen in nature in the past 10,000 years.

Thank you again for this opportunity to address the committee, and I look forward to answering your questions.

[The prepared statement of Mr. Hurrell appears at the conclusion of the hearing.]

Mr. BOUCHER. Thank you, Dr. Hurrell.

Dr. Oppenheimer.

STATEMENT OF MICHAEL OPPENHEIMER, PROFESSOR, GEOSCIENCES AND INTERNATIONAL AFFAIRS, PRINCETON UNIVERSITY

Mr. OPPENHEIMER. Thank you, Mr. Chairman, and I would like to thank the other members of this committee for this opportunity to testify.

In addition to responding to the questions posed by the committee, my testimony addresses the subject of ice sheets and sea level rise which received considerable attention in the wake of the publication of the IPCC report. Finally, I will report some recent findings from the peer-reviewed literature on the question of the time remaining to avoid levels of climate change that some research has characterized as dangerous.

I want to emphasize that I am testifying in my capacity as an individual scientist and not a representative of IPCC or for that matter Princeton University. The conclusions drawn here are my own.

On the first question, are global temperatures increasing, IPCC's answer is unequivocal and I agree, global temperatures are certainly increasing. Furthermore, the warming and the associated sea level rise have accelerated and a pervasive global climate change is underway.

On the second question, to what extent is the increase attribute to greenhouse gas emissions from human activity, here again I fully support IPCC's conclusion that it is very likely that most of the recent climate change is attributable to human activities, particularly the emissions of greenhouse gases and aerosol particles. Natural climate variability and changes in the sun and volcanic emissions have played a much lesser role.

On the third question, how do we expect future global temperatures to be affected by greenhouse gas emissions, during this century global mean temperatures are likely to increase by amounts that are larger and occur faster on a sustained basis than any in the history of civilization and reach levels perhaps not seen in tens of millions of years when ice sheets were much reduced and sea level was much higher than today. The temperature change would be largest on land and at high latitudes which includes large parts of the United States. The climate change is expected to broadly affect key aspects of the climate system and simply put, would remake the face of the Earth.

I am particularly concerned about the fate of the great ice sheets in Greenland and Antarctica. Because our ability to apply modern numerical computer modeling techniques to ice is much weaker than our ability to model the atmosphere, we must rely on other information, particularly from climates of the past. IPCC notes that sea level was likely 13 to 20 feet higher about 125,000 years ago the last time Earth was about as warm as today, actually a little bit warmer, mainly due to the retreat of polar ice when polar temperatures were 5 to 9 degrees Fahrenheit higher than at the present. Additional global warming of only about 3 to 4 degrees Fahrenheit may bring a return of such polar warmth. Accordingly, and here I go beyond the remit of Working Group I of IPCC into the general peer-reviewed literature, I conclude that a warming of no more than 3 to 4 degrees Fahrenheit above present global mean temperatures may represent a plausible objective for avoiding dangerous climate changes.

What does such a limit imply for actions to reduce emissions? The answer is that the chances of avoiding such a warming appear to be less than 50/50 if atmospheric concentrations of carbon dioxide are permitted to exceed 450 parts per million, noting that we are currently around 380 parts per million. Unless the growth in global emissions is reduced soon, first through reductions in emissions in developed countries like the United States, coordinated with or followed closely by measures in developing countries, global temperature is likely to eventually climb beyond the 3- to 4-degree Fahrenheit limit. Then the ice sheets may gradually shrink, causing sea level to rise 13 to 20 feet, possibly over a period as brief as several centuries but possibly over a millennium or more, and if the warming were allowed to continue, that would be only the beginning of a processes that may eventually lead to total loss of both the Greenland and the West Antarctic section of the Antarctic ice sheets and a much larger sea level rise.

Only prompt and sizable reductions in global emissions, hopefully carried out with the leadership of the United States and in collaboration with other large emitting countries such as the EU, Japan, China and India would avoid such an eventuality. I point to the 5-, 10- and 15-year mandatory emissions reduction targets embodied in the proposal from USCAP as plausible initial steps to meet this challenge.

It is apparent to me and I hope to everyone else that the U.S. and all other countries ought to prepare to deal with a warmer world in any event. It is even more important to note that the window of opportunity to avoid potentially dangerous climate outcomes may be closing fast.

Thank you.

[The prepared statement of Mr. Oppenheimer appears at the conclusion of the hearing.]

Mr. BOUCHER. Thank you, Dr. Oppenheimer.

Dr. Hegerl.

STATEMENT OF GABRIELE HEGERL, ASSOCIATE RESEARCH PROFESSOR, EARTH AND OCEAN SCIENCES DIVISION, DUKE UNIVERSITY

Ms. HEGERL. Thank you, Mr. Chairman, and thank you, members of the committee, for giving me the opportunity to testify today about global warming.

To address your questions, I would like to draw your attention to some slides. May I see the first slide, please?

[Slide shown.]

This slide shows you that evidence for warming in the climate system is widespread. The top left panel shows you the observed warming over the 20th century from the surface temperature record, the top right panel, the observed warming from atmospheric temperatures and the bottom shows you warming from the ocean temperature measurements. This widespread nature of the warming and the way it is consistent between different components of the climate system led us to the conclusion that warming of the climate system is unequivocal. Furthermore, the pattern of warming being quite uniform, the warming in each individual component of the climate system being much larger than we expect due to natural climate variability such as El Niño led us to the conclusion that it is extremely unlikely that such a warming in all major components of the climate systems would occur without external forcing, and we also concluded that it is very unlikely due to natural causes alone.

Can I see the second slide, please?

[Slide shown.]

Climate models incorporate our best understanding of how the climate system works and driven with observed changes in radiative force such as changes in greenhouse gases, aerosols, volcanic and solar forcing reproduce the 20th century temperature record quite well. What you see at the top right panel model simulations from a large number of modeling centers and from a large number of models, some of them including smaller forcings like land use change, differing in details of forcing and model physics. The observed warming shown in black lies quite well within the model framework. You can also see that the climate models respond similarly the observations to individual events like volcanic eruptions shown by the gray bars—you can see the records go down a little bit in response to that—and at the bottom panel you see that if driven with natural forcings only such as solar and volcanic forcing, climate models can not reproduce the 20th century warming.

To conclude, however, what caused the 20th century warming, we resort to quite different methods. We do not resort to modeling alone but we try to estimate the effect of the different external influences such as greenhouse gases from the observed change so we look for fingerprints of warming as we expect due to increases in greenhouse gases or other forcings based on these sophisticated studies which focus on the observations allow for the possibility that the response to a forcing could be larger or smaller than anticipated in models, that it could be somewhat different in pattern and it could be not present at all. Carefully investigating alternative physical explanations for the observed warming, we came to the conclusion that it is very likely that most of the observed warming was caused by the greenhouse gas increase. This conservatively accounts for the remaining uncertainty of which we are quite aware.

Can I see briefly the next slide, please?

[Slide shown.]

We can also draw this type of analysis now based on space and time patterns of warming on individual continents, concluding for example that North America is quite outside the range of where we would be due to natural variability alone at this point in time.

Can we move one slide on, please?

[Slide shown.]

The last slide shows you the predicted future warming in the context of the 20th century simulated warming based on observed records of warming from the 20th century from cooling in the last glacial maximum. From various studies we can conclude that the sensitivity of the system to external forcing is not small. Climate responds substantially to changes in radiative forcings such as changes in greenhouse gases. Based on this, we concluded that it is very unlikely that climate sensitivity is less than one and a half, pretty much ruling out various model responses of the climate system in the future and future warming depends on the emissions scenarios we take on and ranks from one and a half to nine times the observed warming over the 20th century.

[The prepared statement of Ms. Hegerl appears at the conclusion of the hearing.]

Mr. BOUCHER. Thank you, Dr. Hegerl.

Dr. Avissar.

STATEMENT OF RONI AVISSAR, PROFESSOR AND CHAIR, DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING, DUKE UNIVERSITY

Mr. AVISSAR. Thank you, Mr. Chairman and members of the committee.

May I have the slides, please? The next one.

[Slide shown.]

The point that I would like to make here as an introduction first of all is that I am not disputing the results or most of the results of IPCC and of my colleagues. In other words, the climate seems to be indicating an increase of the temperature over the past years and IPCC has very eloquently reported on all the studies that demonstrate that. The questions that have been asked in front of us, are global temperatures increasing, I would answer based on the report of IPCC, yes.

The second question, if global temperature increasing, to what extent is the increase attributed to greenhouse gases emission from human activity is where I start having slightly different opinion and so the question, how do we expect the future global temperature to be affected by greenhouse gases. I believe that in spite of the fact that the models are an essential tool to be able to evaluate the climate and are probably the only good tool that we can have to speculate about what is going to happen in the future climate, there are still a lot of uncertainties in these models, and because of those uncertainties and the way that they are built, we have difficulty to estimate exactly what is the proportion of the greenhouse gas contribution to the overall climate versus many other activities that are taking place from the human activity.

On this report of IPCC, I guess that the lower bar that indicates the overall contribution of the human activity indicates an overall contribution with a lot of uncertainty and then the proportion of the different components is where maybe we need to look at a little bit more carefully. In order to do that, I am going to use just a simple representation of land cover change and demonstrate to you how in fact the models that we are using to make these assessments can be mistaken. If I can have the next slide, please?

[Slide shown.]

What you see here is a scenario of deforestation of the Amazon basin, in part due to the intention of investing much more in biofuels as a replacement maybe to traditional oil, and this is a scenario that was produced based on socioeconomic development for 2050, so about 50 years down the road. And you can see here that most of the basin is going to be deforested to be replaced with agriculture areas and other areas. Next slide, please.

[Slide shown.]

The study that we have conducted with models that are better designed to look into those particular processes, higher resolution models, indicates present results that are slightly different than what the global climate models are providing, and what you see here is a sequence of precipitation for the past 30 years—that is the upper graph—that shows that over the past 4 years we had as sequence of high precipitation and then in 1998 a very low precipitation in the Amazon basin, that is showing an El Niño year, and then 2 years that were somewhat close to the average precipitation.

When we use this sequence of precipitation and we feed with the meteorology that has been observed over the area, those mesoscale models, and we combine that with the land cover change, we see the sheet of precipitation that you have on the lower left figure. In other words, what you notice there is that there are areas that receive much less precipitation and in fact the areas that are mostly deforested receive much more precipitation than what was originally obtained.

When you combine all those results and you look at the impact that that has with the global climate models that are currently used versus the original models, you can notice especially, you look the lower right curve, you can notice that in fact the global climate models just for that particular phenomena indicates a difference of precipitation that is twice more severe than what you would get with a model that is better capable of representing the clouds and radiation system. Next picture, please.

[Slide shown.]

All right. The point that we were asked to answer is what do we think is the next direction for research. I guess that I would like to advocate here for better models, and in particular, models that are capable of representing much better the cloud radiation feedback, the models that are capable of representing the biosphere and the hydrosphere a little better and models that can account for process that are extremely significant on the climate system like aerosols, fires and all kinds of other processes that are significant.

So I think that the scientific community is going that direction. I think that we may get some surprises from these models when we can combine all the human activities that we have.

Thank you.

[The prepared statement of Mr. Avissar appears at the conclusion of the hearing.]

Mr. BOUCHER. Thank you, Dr. Avissar.

Dr. Christy.

Mr. BARTON. Mr. Chairman, we have bits and pieces of what the witness just showed us but we don't have it in the coherent form. Could we get him to give that to us?

Mr. BOUCHER. Dr. Avissar, would it be possible for you to reproduce your slides as prints and provide those to the committee.

Mr. AVISSAR. Sure.

Mr. BOUCHER. Thank you, Mr. Chairman, and we will share them with you.

Dr. Christy.

STATEMENT OF JOHN R. CHRISTY, PROFESSOR AND DIRECTOR, EARTH SYSTEM SCIENCE CENTER, NSSTC, UNIVERSITY OF ALABAMA IN HUNTSVILLE

Mr. CHRISTY. Chairman Boucher, Ranking Member Hastert and committee members, I am John Christy, director of the Earth Systems Science Center at the University of Alabama in Huntsville.

I lead a group which builds climate data sets from scratch with interesting results. For example, in constructing surface temperatures in California's Central Valley, we found a dramatic rise in nighttime temperatures that did not occur nearby in the Sierras. This points to a human fingerprint on climate change likely being the massive conversion of dry land to irrigated agriculture and urbanization but not greenhouse gases. In these and other data sets, we find inconsistencies between observations and the output of climate models which tried to tell us the climate effect of greenhouse gases.

Now, I go into detail in my written remarks to answer your questions on temperature changes. Yes, the surface temperature is rising, an unknown portion of which I believe is due to extra greenhouse gases, and the current rate of about 0.15 degrees Celsius per decade is a sensible projection.

Now, the implication of these questions, however, leads me to discuss both climate and energy use. In 1900, the global energy technology supported 56 billion human life-years and that is 35-year life expectancy times 1.6 billion people. It is an index. Today energy technology supports 426 billion human life-years, an eightfold increase, and some of these human life-years are mine. I have been allowed to become a grandparent, a situation that is now the rule, not the exception. An eightfold increase in the global experience of human life, that is a spectacular achievement delivered by affordable energy. It disturbs me when I hear that energy and its byproduct, CO^2, are being demonized when in fact they represent our greatest achievement. Where there is no energy, life is brutal and short. When you think about the extra CO^2 in the air, think also about the eightfold increase in human life.

While preparing this testimony, I was reminded of my missionary experience in Africa. African women collect firewood each day and carry it home for heating and cooking. This inefficient and toxic source of energy kills about 1.6 million women and children a year. When an African woman carrying 50 pounds of firewood risks her life by jumping out in front of my van in an attempt to stop me to give her a lift, I see the value of energy. You see, what I had in my school van in terms of the amount of gasoline I could held in my cupped hands could move her and her firewood 2 or 3 miles down the road to her home. I understood the astounding benefit energy represents and to what extent she and her people would go to acquire it. Energy demand will grow because it makes life less brutal and less short.

The continuing struggle of the European Union and other countries to achieve their self-imposed Kyoto targets, indeed falling behind the U.S. in slowing emissions growth, implies a lot of things but two that stand out to me are, one, underestimating people's demand for energy, and two, overlooking the well-known tendency for countries and industries to game the system for their own benefits without really producing any real emission reduction.

This body is being encouraged to "do something" about global warming and the dilemma begins with this: energy demand will grow because its benefits are ubiquitous and innumerable. The dilemma then is, how can emissions be reduced in a way that doesn't raise energy costs, especially for the many poor people in my State and the world.

There are several new initiatives on energy reductions being proposed as a benchmark. Those which are in the ballpark of the Kyoto-like reductions will produce a small impact on emissions and thus a very, very small impact on whatever the climate does. I have written a number of papers about the precision of our climate records. The impact of Kyoto-style reductions will be too small for we scientists to measure due to the natural variations of climate and the lack of precision in our observing system. In other words, we will not be able to tell lawmakers with any confidence that specific regulations achieve anything in terms of "climate control" in this country or the world. And when you think about it, the climate system is so complicated, we really can't tweak it for a predictable outcome.

So let me close with this observation from my scientific research and life experience. Helping people develop economically is the fastest route I see to giving them the tools they need to adapt to whatever the climate does including that portion of change that may be due to human influences.

Thank you.

[The prepared statement of Mr. Christy appears at the conclusion of the hearing.]

Mr. BOUCHER. Thank you very much, Dr. Christy, and thank you to each of the members of our panel for providing information to us this morning. We have approximately 5 minutes before we must recess the committee for the joint session on the floor. I will take that opportunity to ask my set of questions to this panel.

Mr. BARTON. Mr. Chairman, a parliamentary inquiry?

Mr. BOUCHER. Sure.

Mr. BARTON. What would it take to continue this hearing while the joint session is underway? Would a unanimous consent request allow us to continue, or is it impossible?

Mr. BOUCHER. Mr. Barton, we examined that and I share your desire to continue this hearing. Unfortunately, it is a rule of the House and it is not waivable by our unanimous consent request.

Mr. BARTON. So there is no way?

Mr. BOUCHER. I am afraid there is no way.

Mr. BARTON. Thank you, Mr. Chairman.

Mr. BOUCHER. But thank you for asking.

I would like to get a better sense of where our expert witnesses agree and so let me ask each of you if you would to respond to this group of questions, and for purposes of brevity, a simple yes or a no would be desirable by way of response.

First question: In the executive summary that was released in February, the IPCC found that—and I quote from the report—"Most of the observed increase in global averaged temperatures since the mid–20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations," in other words, those concentrations that came from human activity.

Do you agree or disagree with that conclusion, Dr. Hurrell?

Mr. HURRELL. Yes, I do agree with that conclusion.

Mr. BOUCHER. Dr. Oppenheimer?

Mr. OPPENHEIMER. I agree.

Mr. BOUCHER. Dr. Hegerl?

Mr. HEGERL. I agree. My chapter proposed that conclusion.

Mr. BOUCHER. Dr. Avissar?

Mr. AVISSAR. I cannot answer by yes or no. I would say that I tend to agree, but I am not convinced.

Mr. BOUCHER. OK. So you lean in favor of that finding?

Mr. AVISSAR. I am sure that there is a contribution from the greenhouse gases. I have no doubt about that.

Mr. BOUCHER. That is good. Thank you, sir.

Dr. Christy?

Mr. CHRISTY. A similar answer, the contribution from greenhouse gases, but I don't know how much.

Mr. BOUCHER. All right. I would note that the IPCC defines "very likely," which is the language used here, as a 9 in 10 chance that the finding is accurate.

Question No. 2: The IPCC also found that—and again I quote from the report—"Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those that were observed during the 20th century." Do you agree or disagree, Dr. Hurrell?

Mr. HURRELL. Yes, I do agree with that.

Mr. BOUCHER. Dr. Oppenheimer?

Mr. OPPENHEIMER. I agree.

Mr. BOUCHER. Dr. Hegerl?

Mr. HEGERL. I agree.

Mr. BOUCHER. Dr. Avissar?

Mr. AVISSAR. Not enough information to answer.

Mr. BOUCHER. All right.

Dr. Christy?

Mr. CHRISTY. I think since we are starting at a warm spot that the changes will continue.

Mr. BOUCHER. All right. Thank you.

Now, one additional question that I will ask and I will ask for a little bit of comment from you on this one. Dr. Avissar has testified that regional climate models could be improved by incorporating the effects of land use in the area for which that regional modeling is being performed. Assuming that you agree with Dr. Avissar, do uncertainties about land use effects or other regional uncertainties diminish either our understanding of how greenhouse gases affect global warming or the justification for reducing greenhouse gases? And I would ask you not only do you agree but why or why not.

Dr. Hurrell?

Mr. HURRELL. Thank you. Yes, I do agree with Dr. Avissar's testimony on this point. As several of us have pointed out, global climate models are very valuable tools. They are not perfect and they can certainly benefit, as I pointed out explicitly, from further and more complete considerations of, for instance, land surface change and land surface forcing. Regional models are one avenue to begin to include those processes more completely and the field is moving in that direction. With respect to your bottom-line statement, Mr. Boucher, I believe that the global climate models indeed given their very impressive simulations of the observed hemispheric scale and larger-scale temperatures, that is evidence that many of the key processes are indeed correct in the large-scale models and therefore I believe that the evidence is very convincing that the range of changes that we have seen goes beyond the range of natural variability and can be attributed to anthropogenic influence on large-scale climate but certainly regional processes do need to be included better. As we begin to try to make comments on regional and local scale changes, the role of natural variability becomes larger and there are uncertainties in our understanding at that level.

Mr. BOUCHER. Thank you very much.

Dr. Oppenheimer?

Mr. OPPENHEIMER. I would generally agree with Dr. Avissar and I would add, by the way, that we need to improve our ability to model the ice sheets and that is a critical component to understanding sea level rise. I have substantial amount of confidence in the statements about the importance of the greenhouse gases, the projection of future climate and the attribution of recent climate changes, not only because of the global models and their ability to reproduce past climate changes of, say, the last 150 years but also because of the wealth of paleoclimate data, that is, data on climate history, which basically supports general conclusions from the atmosphere, ocean general circulation models.

Mr. BOUCHER. Thank you, sir.

Dr. Hegerl?

Mr. HEGERL. I agree with Dr. Avissar's testimony that it is very important for regional predictions, for reliable regional predictions to think about land-use change and incorporated also for reliable predictions of rainfall changes. I do not think that these changes have a big impact on large-scale temperature predictions nor do they affect our assessment of what caused the 20th century warming.

Mr. BOUCHER. Thank you.

And Dr. Avissar, let me just modify the question for your purposes. I think we are all acknowledging, your colleagues are, that there are uncertainties about the accuracy of regional models based upon particular land uses in the area which are not properly incorporated into those models but the real question is, does that uncertainty affect our understanding of climate change on a global basis, and should that uncertainty about the regional modeling in any way affect our decision-making about whether it is proper to go forward or not with any kind of control measures?

Mr. AVISSAR. And I appreciate that. The point that I want to raise here is that I am using the land cover, the original scale, just as an example to illustrate what is happening. The truth is that the complexity of the climate system and it is a chaotic system and we do not know exactly how it is going to evolve. We use that with models that are idealized. There are a lot of problems in those models. The type of interactions that we are talking about that have to do with the land cover but with many other processes and it is probably one of the most severe ones.

Mr. BOUCHER. Thank you, Dr. Avissar. I am afraid time will not permit any further explanation but we understand your response.

Dr. Christy?

Mr. CHRISTY. We have rebuilt data sets in three parts of the world very carefully. Climate models don't come close to what actual observations have shown so I have a bit of a disagreement with the notion that even though climate models get some big number right that they don't get the smaller regions right. So I do agree with Dr. Avissar's point that the regional expectations of current models—or regionalization is a way to improve these global climate models.

Mr. BOUCHER. Thank you very much. My time has more than expired.

The joint session, I assume is underway, although I do not see bells having rung. Do we have any information about that? It was supposed to convene at 11:00.

Mr. BARTON. I am ready to keep going.

Mr. BOUCHER. I am ready to keep going too but I think we have to observe the rule.

Mr. BARTON. I won't tell.

Mr. BOUCHER. Why don't we say——

Mr. BARTON. It has not started, my staff says.

Mr. BOUCHER. It has not started?

Mr. BARTON. No, sir.

Mr. BOUCHER. I think the best course for us at this point is in fact to recess, and my apologies to our witnesses for this. I hope your patience will enable you to remain here and answer additional questions my colleagues will propound. Let us reconvene 5 minutes after the joint session has concluded. The subcommittee stands in recess.

[Recess.]

Mr. BUTTERFIELD [presiding]. Come back to order.

I was not in the session this morning. I understand that the witnesses have already testified and we have started the questions. Have we done the opening statements? We have done the opening statements.

Let me thank all of you for your patience. This has been a disjointed morning this morning. I am sure you have been informed that we had a special session of Congress this morning at 11:00 and we have just completed that and now we are back to work.

At this time the Chair will recognize the distinguished gentleman from Illinois, Mr. Hastert.

Mr. HASTERT. Thank you, Mr. Butterfield. I appreciate that, and again, I appreciate all the patience of our people who are witnesses who are here to testify today.

Mr. Oppenheimer, in your statement you were talking about the polar ice fields, specifically in Antarctica, and talking about the thickness of the sheets and the possibility of I think it is 1,000 years that they may melt. Hasn't the temperature actually in the South Pole not been affected?

Mr. OPPENHEIMER. We really don't have a good picture of what temperatures have done over the last 100 years for the continent as a whole. We know that temperatures have warmed on the Antarctic peninsula which is the furthest north point and we know that the limited number of stations, and I think it is really only two inland away from the coast did cool for some period of time. There is some indication that that trend is reversing. So my own judgment on that, and there is not complete agreement on this in the community, is that we cannot make a statement about what the Antarctic continent as a whole has done over the past century. There simply isn't enough data.

Mr. HASTERT. Then if we are talking about the ice fields at the South Pole and Antarctic, we need to be careful about what we say.

Mr. OPPENHEIMER. We need to be careful about how we represent what has happened in the past. There is no question about that.

Mr. HASTERT. And what happened in part is hard to have the prognosis. It almost has to happen in the future.

Mr. OPPENHEIMER. We have some idea of what happened in the very distant past, not a very firm idea, and we have a better idea of what happened in the distant past for Greenland. So would you like me to elaborate?

Mr. HASTERT. Well, I am short on time here so I appreciate your answer.

Dr. Christy, in your report and your testimony about land use and agriculture changes in the Central Valley of California, that they had an impact on temperature and that you are starting to see this in other work. When we hear about rising temperatures and other climate changes, should we keep in mind that that land use may play a more significant role than we have talked about?

I come from the Midwest, an agricultural district, and in April when the fields are plowed and you are ready to plant corn and soybeans, everything is black. Heat is absorbed by that black loam and then of course and by the end of May, and the first part of June, it is covered in green. It changes. What is the effect?

Mr. CHRISTY. Well, as a graduate of the University of Illinois, I have seen those same fields, and what we found at least in the study we have done in California and also now in Africa that you alluded to is that that is explaining the largest changes that are occurring there, that it is not something that can be affected by greenhouse gases. It is something that the way in which the warming occurs. It is related to what humans are doing to the landscape, not to the atmosphere.

Mr. HASTERT. Dr. Avissar, again, another phenomenon that exists are clouds. some clouds have a cooling effect, some clouds have a heating effect. They hold heat in. Can you explain how clouds are treated in the models and are they approximated and we can trust the many approximations of real process and models to faithfully simulate the real world over decades?

Mr. AVISSAR. Our understanding of the cloud system is still relatively limited, OK. We have some moderate understanding of the way that the models of the way that the clouds are behaving and we are using that understanding to put that into our models so I would say that the best in our models we have a moderate capability of representing the cloud system. It is done not very well.

Mr. HASTERT. Dr. Christy, the average daily temperatures, you suggest in your testimony, are more reliable measures of the effects of greenhouse gases in the atmosphere. What do these findings suggest about the relative role of carbon dioxide and climate change if the research holds up?

Mr. CHRISTY. OK. The point here is that the temperature that occurs at the maximum warming in the afternoon is more closely related to the deep atmosphere and therefore to what greenhouse gases are doing to the atmosphere and those trends are less than what you see in surface temperature maps, for example, that were shown earlier. So that indicates that if that is the signal of what greenhouse gases are doing in the atmosphere that that is a smaller signal than we have been led to believe at this point.

Mr. HASTERT. Thank you. My time has expired.

Mr. BUTTERFIELD. The gentleman's time has expired.

Let me just again thank each one of you for coming today. We are going to be completing this hearing this afternoon and hopefully all of the Members will come through and have an opportunity to ask their questions.

But let me direct my question very briefly to Dr. Hurrell. Dr. Hurrell, as many of the members of this committee can attest, we have been around for a long time including the decade of the 1970's and during that period of time we were given many warnings, many pessimistic warnings that the planet was cooling. That was the advice that was given to us by scientists during that era, and then they ask why given how wrong the scientists were back then, at least some of the scientists were back then, why we should trust the scientists now when we talk about global warming. How do we explain that the science is now different than it was in the 1970's?

Mr. HURRELL. Thank you very much. There were a handful of scientists who were taking about a global cooling signal and potential causes for that. A key aspect of this is that the climate system does vary and it varies for both natural as well as anthropogenic reasons. The fundamental difference now is that unlike in the mid–1970's when a few scientists were talking about this, we are talking about much stronger evidence now, much better understanding and an entire climate community or almost an entire climate community who is in agreement on the major points. There have been the IPCC assessments. There has been National Academy of Science reports. There has been U.S. Climate Change science program results and the like that all speak to these general conclusions that we are talking about today. This is quite different from the situation in the 1970's where there simply was not nearly as comprehensive and expensive look at what could have been causing that bit of global cooling that we saw really from a peak in the mid–1940's into the mid–1970's.

Mr. BUTTERFIELD. We have just been joined by the gentleman from California, Mr. Waxman, and he has informed the Chair that he is going to have to leave very shortly and so I am going to yield the balance of my time with the unanimous consent of the other side to Mr. Waxman, in addition to his time.

Mr. WAXMAN. Thank you very much, Mr. Chairman, and I hope you will reclaim your time later because I know you are being very kind to me in letting me go forward here.

At several of the hearings, some Members have wondered how important human-caused greenhouse gas emissions are when there are even larger amounts of naturally occurring greenhouse gas emissions each year.

Dr. Hurrell, can you help us understand this? Can you explain why human-caused emissions are so important even though every year there is a greater volume of naturally occurring emissions?

Mr. HURRELL. Absolutely. Thank you. Yes, there is a large volume of naturally occurring carbon dioxide emissions by natural processes in the climate system. These have occurred of course throughout time. The key way to think of this problem I believe is that the natural system has both sources and sinks and it maintains a balance in terms of the natural system. Therefore, even though the human contribution in terms of a percentage might be relatively small to the total amount of carbon dioxide in the atmosphere, it is very significant because it is upsetting this natural balance. It is basically throwing the system out of whack and so it provides a very important radiative forcing on the climate system that the climate system must adjust to and it does that by way of warming, among other changes.

Mr. WAXMAN. Dr. Oppenheimer, from what I heard from Dr. Christy, he seems to be saying—and correct me if I am wrong—that this latest report from the Intergovernmental Panel on Climate Change diminishes some of the reasons to be concerned about the impacts of climate change. For example, he stated reductions in the scariest realization of sea level rises are welcomed. I am concerned about the accuracy or your views of that position.

Mr. OPPENHEIMER. What IPCC did in this report is to narrow the range of uncertainty on future sea level rise so that the lowest projection of possible sea level rise has been raised and the projection of highest plausible sea level rise within 90 percent confidence has been lowered. On the other hand, IPCC was very careful to note that its projections do not account fully for processes that we know are going on in Earth's ice sheet in Greenland or in West Antarctic and so those projections have to be regarded themselves as relatively cautious because they assume the ice sheet will not continue to accelerate their loss of ice into the sea, which increases sea level.

Mr. WAXMAN. It is my understanding the IPCC's sea level rise projection only includes the melting of glaciers and the increased volume of the oceans due to the absorption of greater warmth. Is that correct?

Mr. OPPENHEIMER. Not quite. There is an attempt to account for the fact that over the last decade ice in both Greenland and parts of Antarctic have started to move very rapidly into the sea. Those are called dynamical changes because they are flows like rivers flow. The ice flows like rivers in certain spots. The IPCC added to its melt this approximation to sea level rise that you get from just looking at melting a small amount to account for these extra flows that are occurring in the rivers of ice coming off the continents but it did not make any estimate for what could happen if those flows increase in the future and there is a significant risk that those rates of ice flow will in fact increase.

Mr. BUTTERFIELD. Let me ask you to suspend for just a minute, please. The gentleman's time has expired, and with the unanimous consent of the minority, I would ask that Mr. Waxman be allowed to continue with his regular time.

Mr. BARTON. Point of parliamentary inquiry.

Mr. BUTTERFIELD. Yes, sir.

Mr. BARTON. I am not going to object. I know people are busy, but would this mean Mr. Waxman would get 5 minutes and then we would get 5 minutes for our side.

Mr. BUTTERFIELD. The gentleman had 8 minutes because he did not exercise his right to an opening, so it is 3 plus 5.

Mr. BARTON. Three plus 5 or 3 plus 8?

Mr. BUTTERFIELD. Three plus 5. Yes. The gentleman requests 5 minutes. All right. The gentleman is recognized for 5 minutes.

Mr. OPPENHEIMER. So my point is that in one sense the IPCC projections are regarded by many scientists as conservative because they are unable to account for the accelerated loss of ice into the sea that we know is occurring. We don't have a model that can tell us how to project those sorts of changes. The best we can do is look at what happened in past climates a long time ago when the poles were somewhat warmer than today and see what the fate of the ice was. What we know is, the Greenland ice sheet was significantly smaller and sea level was 4 to 6 meters higher, about 13 to 20 feet. We don't know how fast that occurred. We don't know whether that process has already been triggered in fact.

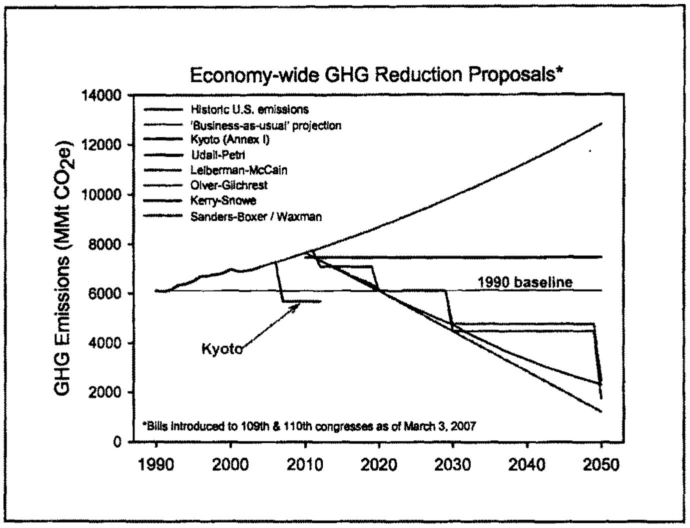
Mr. WAXMAN. So in your view, you don't see any reason that this most recent IPCC report should make us less concerned about the impacts of climate change than we previously believed?

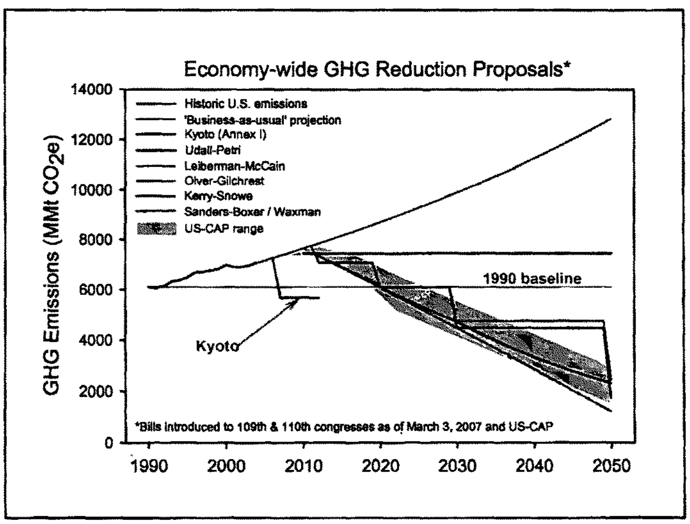
Mr. OPPENHEIMER. Overall, it makes me more concerned, and the things that are quite uncertain in the report make me concerned because they are uncertain and they could wind up either turning out smaller or they could turn into very, very big hazards in the future.

Mr. WAXMAN. Dr. Christy, in your testimony you also discuss some new proposals to control greenhouse gas emissions that are in the "ballpark of the Kyoto-like reductions." You state that these proposals would have a very small and perhaps undetectable impact on preventing climate change. One of the industry's strongest criticism of the Kyoto protocol was that it wouldn't solve the problem. Under the Kyoto protocol, the developed world would take one step toward emissions reductions by 2012. However, these reductions alone were not enough to solve the problem and of course industry was concerned about what unknown targets they might face after 2012. When you include the lack of targets for the developing world, I can see why you would say it is hard to predict the climate outcomes associated with Kyoto. Fortunately, we have moved beyond the Kyoto debate.

I have a chart that shows the emissions targets for the greenhouse gas reduction bills that have been introduced in the 109th and 110th Congresses. Would you say that any of these bills are in the ballpark of the Kyoto-like reductions?

[The chart follows:]


Economy-wide GHG Reduction Proposals*
GHG Emissions (MMt CO2e)
Historic U.S. emissions
'Business-as-usual' projection
Kyoto (Annex I)
Udall-Petri
Leiberman-McCain
Olver-Gilchrest
Kerry-Snowe
Sanders-Boxer / Waxman
1990 baseline
Kyoto
*Bills introduced to 109th & 110th congresses as of March 3, 2007
0
2000
4000
6000
8000
10000
12000
14000
1990
2000
2010
2020
2030
2040
2050


Economy-wide GHG Reduction Proposals*
GHG Emissions (MMt CO2e)
Historic U.S. emissions
'Business-as-usual' projection
Kyoto (Annex I)
Udall-Petri
Leiberman-McCain
Olver-Gilchrest
Kerry-Snowe
Sanders-Boxer / Waxman
US-CAP range
1990 baseline
Kyoto
*Bills introduced to 109th & 110th congresses as of March 3, 2007 and US-CAP
0
2000
4000
6000
8000
10000
12000
14000
1990
2000
2010
2020
2030
2040
2050

Mr. CHRISTY. This is just for the United States, right?

Mr. WAXMAN. Yes, bills introduced in the Congress here.

Mr. CHRISTY. I don't know if I can understand the question. Kyoto is the red and it looks like two and three intend to go beyond Kyoto out to 2030 or 2040. I mean, I am just reading the chart.

Mr. WAXMAN. Right.

Mr. CHRISTY. But I think my point would still be the same, is that since this is only the United States, that our ability and our observing system is not capable of saying here is a change that we can confidently attribute to one of these bills.

Mr. WAXMAN. At least five of the bills introduced are not Kyoto-like. Let us assume that the U.S. commits to emissions cuts in the range called for by these five bills and let us assume that on this basis the U.S. positions itself as a world leader and convinces other nations to undertake similar emissions cuts.

Dr. Hurrell, do you agree that this range of emission cuts on this time frame will have a measurable effect on the climate?

Mr. HURRELL. I personally believe it is essential that these kind of trajectories are adopted. I believe that while there are uncertainties in our knowledge, as we have already discussed widely today, we know quite a bit and I think that the potential consequences of global climate change are important enough that these kind of reduction proposals should be adopted. I agree with your statement that the United States can play a leadership position in convincing the rest of the world to go along. It has to be a global solution. It can't be something that we do alone.

Mr. WAXMAN. Dr. Hegerl, based on your expertise on climate forcing, would emission cuts in the range of 65 to 80 percent over the next 45 years have a measurable effect on the climate?

Ms. HEGERL. Can I have the last figure of my testimony, please?

Mr. WAXMAN. Sixty-five to 80 percent over the next——

Ms. HEGERL. Oh, no, the last figure of my figures, please. Next one. So what you see here is in yellow is the lowest limit of what we can do physically. This is if we would freeze concentrations at the present time and what you see in colors are the various emissions. So any bill that would reduce emissions beyond the lowest emission there will have a big impact on future global temperature rise and with it on the impact global warming can make quite a bit of difference because impacts are expected to correlate somewhat with the global mean temperature increase.

Mr. BUTTERFIELD. The gentleman's time has expired.

Mr. WAXMAN. Mr. Oppenheimer, do you have anything on that as I ask my last question?

Mr. OPPENHEIMER. Yes, I agree, it would have an effect, particularly since the U.S. taking leadership I think would bring other countries along and then we would have a serious global reduction.

Mr. WAXMAN. Thank you.

Thank you, Mr. Chairman.

Mr. BUTTERFIELD. The gentleman's time has expired.

The gentleman from Texas, the ranking member of the full committee, is recognized for 5 minutes.

Mr. BARTON. Mr. Chairman, before I use my time, I would ask Dr. Hegerl or Dr. Oppenheimer to provide us with a copy of the actual report. They keep referring to it. All we have is the summary and this is the 2001 report. What we have is about a 10-page summary. They have seen it; we haven't. I think we need the report and have it in the record of this hearing or at least have it available for members of the subcommittee.

Mr. OPPENHEIMER. Could I comment on that? I have been careful in my testimony to refer only to what is in the summary because the actual details are not going to be available until May. I wish they were available today but I don't——

Mr. BARTON. Well, your testimony was so specific, you are bound to have seen the report. There is no way you could say some of the things you have said if you haven't seen the report.

Ms. HEGERL. The U.S. Government has commented extensively on the draft report so it has seen the draft reports and——

Mr. BARTON. Well, we are part of the U.S. Government and we——

Ms. HEGERL. Yes, so you could——

Mr. BUTTERFIELD. Point of order. Will you make the report available when it is available?

Mr. OPPENHEIMER. Certainly.

Mr. BARTON. It is something available now, Mr. Chairman.

Mr. BUTTERFIELD. When do you estimate that to be?

Mr. OPPENHEIMER. It will be published publicly in May. I don't have the power or the authority to release the report.

Mr. BARTON. But you have read it.

Mr. OPPENHEIMER. I have read it but I have been—first of all, it may change in some respects between now and May. Second of all, I have been extremely careful, as I think these people have been too, to refer only to items which can be defended by looking at the summary, which is public. Do you want me to go over that point by point? I would be happy to.

Mr. BARTON. Mr. Chairman, were based on more than this summary. I have read the summary.

Mr. BUTTERFIELD. Let me ask the gentleman to suspend. This has extended beyond a parliamentary inquiry. I am going to recognize the ranking member for 5 minutes.

Mr. BARTON. Well, I want some definition about how we are going to get a copy of this report.

Mr. BUTTERFIELD. Well, the gentleman has said it is not available and he will make it available when——

Mr. BARTON. Well, if it available to those people and it has been available to parts of the executive branch, it should be available to members of this subcommittee under some conditions that are acceptable to both the majority and the minority. I am not saying we are going to publish it but I think we ought to have it available. That is the whole purpose of this hearing.

Mr. BUTTERFIELD. From the majority side, if the report is available, we will certainly accept it and make it available.

Mr. MARKEY. Will the chairman yield briefly?

Mr. BUTTERFIELD. Yes, the gentleman from Massachusetts.

Mr. MARKEY. The Bush administration has a copy of the report. I recommend that our committee ask the Bush administration to give us a copy of the report, which they have, and I would make the request from the committee.

Mr. BARTON. Again on my parliamentary inquiry, according to our speaker of the legislative branch, we are supposed to produce a bill by June. It is early to mid-March. Fifty people contributed to this report, according to the summary sheet. Only one is with us, Dr. Hegerl, and yet we are asked to make major policy decisions on our economy without seeing the base documents. That is an impossible situation to put the Congress in.

Mr. BUTTERFIELD. Well, it is an impossible situation to put the witness in. He said that it is not available and he will make it available when it is plausible.

Mr. BARTON. I am not recommending this, Mr. Chairman, but I believe if we subpoenaed the report, we could get it.

Mr. BUTTERFIELD. All right. Your comments are in the record.

The gentleman may resume.

Mr. BARTON. Well, start the clock for me, Mr. Chairman.

Mr. BUTTERFIELD. All right. Let us restart the clock. 5 minutes.

Mr. BARTON. My first question I think is going to be to Dr. Hegerl. On page 2 of the summary, down in the middle of it, it says that carbon dioxide is the most important anthropogenic greenhouse gas. I am probably mispronouncing anthropogenic but that means manmade. What is the most important greenhouse gas, period, not just manmade but in totality, natural or manmade?

Ms. HEGERL. That would be water vapor.

Mr. BARTON. Water vapor. And what percent of water vapor is manmade?

Ms. HEGERL. I would defer. I would just repeat what Dr. Hurrell just said. Water vapor is a very powerful natural greenhouse gas. It would have quite substantially cooler temperature on Earth if it weren't for the natural greenhouse gas water vapor. Adding CO^2 to the atmosphere changes the balance, the heat balance of the planet.

Mr. BARTON. My understanding is that water vapor is 95 percent of the greenhouse gas. Would you agree with that?

Ms. HEGERL. I don't know the exact numbers.

Mr. BARTON. All right. My understanding is that water vapor is about 95 percent and that manmade carbon dioxide is about 4 percent. Does anybody on this panel dispute that?

Ms. HEGERL. No, but we are changing the balance, the overall balance.

Mr. BARTON. But you will agree that of greenhouse gases, water vapor is well over 90 percent and manmade CO^2 is under 5 percent? That is a factor of approximately 20 to 1.

Mr. OPPENHEIMER. Could I clarify? I think what you are referring to is the natural emissions of carbon dioxide are about 95 percent of total emissions and the human emissions are at 4 percent of total carbon dioxide emissions.

Mr. BARTON. Well, I think we have to have some perspective because this report, the summary of the report that nobody has seen except for 50 very important people and maybe a few in the Bush administration is based on manmade emissions. In point of fact, natural emissions overwhelm manmade emissions.

I want to go to page 4 of the summary. I am going to ask Dr. Christy a question. These radiative forcing components in the charge on page 4 are in watts per meters square. They only list manmade forcing components. Is that the way you read that chart?

Mr. CHRISTY. Yes.

Mr. BARTON. OK.

Mr. CHRISTY. Except for the solar forcing.

Mr. BARTON. Now, what is the most important radiative forcing component in totality in terms of temperature change?

Mr. CHRISTY. Well, you would start with the sun and then the water vapor in the atmosphere and clouds and so on are the biggest——

Mr. BARTON. And if the manmade component has a positive total net radiative forcing change of about 1.5 or 1.6 meters squared, if we put the same kind of table for clouds, where would that be on the chart?

Mr. CHRISTY. It would be about this far out from the page.

Mr. BARTON. We can't put "this far out" in the record. In terms of watts per meters squared, where would it be?

Mr. CHRISTY. The net effect would be in tens of watts per meters squared.

Mr. BARTON. Tens of watts. Now, is water vapor the same thing as clouds?

Mr. CHRISTY. I am talking about the total impact of that.

Mr. BARTON. Dr. Hegerl or Dr. Hurrell, do you disagree with what Dr. Christy just said?

Mr. HURRELL. I agree that water vapor is the dominant greenhouse gas.

Mr. BARTON. And do you agree that in order of magnitude, it is 100 times larger than the net manmade effect?

Mr. HURRELL. I am not sure about the factor of 100. I believe, as I said, that those are very large effects, that the natural system is in balance so the emphasis on the anthropogenic part is because it throws the natural balance out of whack. That is why the anthropogenic component is important.

Mr. BARTON. Now, my next question I guess will be to Dr. Hegerl. Again, back on page 2 down in the footnotes, the very last sentence says that a number of uncertainty ranges in the Working Group I third assessment report corresponded to 2-sigma, 95 percent, often using expert judgment. Does that mean that the uncertainty range is close to 100 percent?

Ms. HEGERL. No, that just defines which uncertainty ranges are given conventionally in the report.

Mr. BARTON. Well, but if you have a normal bell curve, 50 percent is right in the middle and then you have these ranges. Each sigma range goes out from the center. If I understand correctly, if you have got a 2-sigma difference, you could be 100 percent off or 50 percent off either way. Or my statistics wrong? And I could very well be wrong. It has been a long way since I took statistics in college but that is the way I remember it. When I view it, this basically says you all could be way off even using expert judgment. Is that what that says?

Ms. HEGERL. The 95 percent range indicates a chance of five out of 100 or one in 20 to be outside that range, which is a quite small chance.

Mr. BARTON. Mr. Chairman, my time has expired. Are we going to have a second round?

Mr. BOUCHER. Well, I think that depends on how long the first one goes and how busy members are and how patient the panel is willing to be. So the answer is undetermined at this time. We will see.

Mr. Markey is recognized for 8 minutes.

Mr. MARKEY. I thank the Chair very much.

The average temperature for a human being is 98.6. You increase our temperature by 3 degrees, that individual now has some problems. They are visiting the doctor, just the 2- or 3-degree change. Or to think of it another way, on a seesaw, there is 1,000 pounds on one side and 1,000 pounds on the other side. It is an equilibrium. But you put 20 more pounds on one side or the other and it throws the whole system out of whack, and that is essentially what is happening whether it be human temperature or it be nature itself. When you have relatively small changes in something that is in equilibrium, you get rather dramatic changes in terms of the whole direction of a seesaw or a human being's health.

So Dr. Oppenheimer, in your testimony you suggest that the greatest impact of global warming on the United States and for the world may come from rising seas. But you also say that there is a lot of uncertainty about how the ice sheets in Greenland and Antarctic will behave as the planet continues to warm up. If both the Greenland ice sheet and the West Antarctic ice sheet were to melt, you say we could see a 40-foot increase in sea levels, 23 feet and 17 feet. What would be the consequences of that kind of rise in sea levels, Doctor?

Mr. OPPENHEIMER. A 40-foot rise would, for instance, bring the Gulf Coast up to about the level of Houston and all the land between that and the current Gulf Coast would be submerged. A third to about half of Florida actually would be permanently submerged. It would be a world-shaking change. I want to emphasize that I don't think any scientist thinks that that kind of sea level rise could play out totally in a matter of even a century. It would take at least, by my own reckoning, four or five centuries at minimum but the rates of sea level rise between now and then would be staggeringly high. They would be on the order of a couple of meters per century. We can't deal with that.

Mr. MARKEY. So you note that the IPCC projection of a 7- to 15-inch increase in sea level excludes rapid dynamical changes in ice flow. Why was that excluded? Was it because the IPCC felt those kind of changes were unlikely or because scientists didn't know how to model them yet?

Mr. OPPENHEIMER. It was because scientists at the current time do not have a model and you need a model to project forward. They do not have a model that can accurately reproduce what has happened to the ice sheets recently in the last few decades and therefore they do not trust the projections of those models in terms of projecting the behavior of the ice sheets over the next several decades and certainly not over the next several centuries. So at this point there is a lot of scurrying around in the community of glaciologists to try to better understand what our observations of the ice sheets mean, to construct an advanced model to be able to project better, and to interpret climates of the past to tell us what they say about what the ice sheets did when Earth was warmer a long, long time ago.

Mr. MARKEY. So would it be fair to say that there is an unknown unknown out there with respect to the melting of those polar ice sheets that could make the problem much worse than what the IPCC has found thus far?

Mr. OPPENHEIMER. I think you are drawing on former Secretary Rumsfeld's description of uncertainty and I would rather refer to it as a known unknown than an unknown unknown.

Mr. MARKEY. But is it a fair conclusion to say that is possible?

Mr. OPPENHEIMER. Yes.

Mr. MARKEY. Regardless of the description of it, is the conclusion accurate?

Mr. OPPENHEIMER. I am sorry. Could you repeat what the conclusion was? I got lost in the metaphor.

Mr. MARKEY. Is there an unknown out there or a known unknown, as you want to describe it, that the melting of the ice sheets could be far worse than the IPCC report?

Mr. OPPENHEIMER. Yes, that is certainly true.

Mr. MARKEY. OK. Well, that is the important thing to get on the record.

Mr. MARKEY. For the other panelists, how concerned are you about a possible disintegration of the Greenland and West Antarctic ice sheets, and do you concur with Dr. Oppenheimer's testimony that loss of large parts of the polar ice sheets and a very large sea level rise over the course of several hundred years rather than over a millennium would occur once the world warms up as little as 3 or 4 degrees Fahrenheit. Do you all agree on that?

Mr. HURRELL. I will speak just very briefly. Yes, I agree. I agree with Dr. Oppenheimer's main points and again, I point to the paleoclimatic evidence going back where we know that for instance in the last interglacial, much of the Greenland ice sheet was melted and sea levels were indeed much higher than they are today and so I think that is a very real possibility.

Mr. MARKEY. Thank you.

The other witnesses quickly?

Ms. HEGERL. I agree with the overall statement too and I would like to remind that the lower limit of sea level rise is largely driven by factors we understand much better than the disintegration of ice sheets. For example, the simple temperature effect on ocean water expanding. So the lower limit is far less uncertain than the upper limit.

Mr. MARKEY. Thank you.

Mr. AVISSAR. Yes, if there is warming, the ice sheet will melt and that will increase the sea surface level, no doubt.

Mr. MARKEY. Dr. Christy?

Mr. CHRISTY. This is a very complicated issue but I would like to say that a thousand years ago, Greenland was much warmer than it is today for centuries at a time and yet it evidently did not experience any kind of dramatic change at that point.

Mr. MARKEY. Thank you. Let me move to you then, Dr. Christy. On page 8 of your testimony and in your oral testimony, you said, "It disturbs me when I hear that energy and its byproducts such as CO^2 are being demonized when in fact they represent the greatest achievement of our society. Where there is no energy, life is brutal and short," and you are quoting of course the famous philosopher, David Hobbs, who actually said that life for man in a state of nature was nasty, brutish and short but Hobbs, Doctor, was actually arguing for the need to have governments in place to address the needs and wants that make this so, lack of food, lack of security, et cetera. For Hobbs, government was the leviathan, a huge beast, but he argued that it was a necessary beast so our challenge is whether governments will respond to the challenge that scientists are opposing right now. If we fail, we may well return to a Hobbsian state of nature, brutal and short, but that is the point he was making, that governments must then work to minimize it. So to the extent that yes, science does demonize, science has demonized asbestosis. Science has demonized tobacco. Science has demonized exposure to radiation. It doesn't mean that they all don't have a role but the warning comes as to what the negative consequences are as well and so if you want to characterize that as demonization, I think you have a right to do so but I think you misquote Hobbs and I also think you understate the role historically that science has played, Doctor, in giving us the warnings not just of the benefits of science, the benefits of technological advancement but also the negative consequences. So there is a Dickensian quality, in other words. It is the best of technologies and the worst of technologies simultaneously. It can both do good and harm at the same time, and I would just appreciate your comment on that.

Mr. CHRISTY. OK. I didn't see or hear a question but I think the basic thing I want to——

Mr. MARKEY. No, I asked for a comment.

Mr. CHRISTY. OK. The basic point I wanted to get across was that people like me are alive today and you as well because of the technologies energy has brought us and because of that CO^2 that is in the atmosphere now and that is a point that needs to be really emphasized, and in my experience in Africa, I keep going back to that because energy demand will rise tremendously. We see it right now in those countries. And when I saw that chart up there about the U.S. emissions, I don't think any of those are going to happen, but when you throw in the rest of the world, I don't see how something short of a global recession or depression would cause CO^2 emissions to fall.

Mr. BOUCHER. Thank you very much, Dr. Christy.

Thank you, Mr. Markey.

Mr. Shimkus for 5 minutes.

Mr. SHIMKUS. Thank you, Mr. Chairman. And I have enjoyed this. I am old Army infantry guy and we had the acronym—it is not politically correct but it is "Keep it simple, stupid," the KISS formula, and that is what a lot of us try to make through all this science and stuff. I also, at the risk of being defined as a Neanderthal, because a lot of this is secular humanist debate, I am a creationist so I believe in the big picture; God is in control, but God also calls us to be good stewards, and I think that is kind of par of this debate which I don't mind and I think it is going to be helpful because Mr. Christy's comments about life in a carbon world and the benefits provided by a carbon world is undeniable. The life that we live as middle-class Americans—maybe I am not in that category anymore but my family sure was when I was being raised—because electricity and power allowed us to have a standard of living that, I am one of seven kids, probably half the kids would have died in the Middle Ages if it weren't for the carbon world in which we live, and we can't just throw that out of this debate, which brings up a lot of great questions because we hear the term "balance" so the first question—and really, the only way we are hearing so far about balancing is capping carbon dioxide, capping emissions of carbon dioxide and whether that is arguable or not, whether we can do it or even maintain it. Is there a way to put a balance without capping carbon dioxide? Why don't we just go quickly though because I don't have that much time.

Dr. Hurrell, do you think there is a way to reclaim this balance without—my staff is going to have to give me the formula, CO^2 and all the different strata of the atmosphere and what is going on. Can we emit something up into the atmosphere to help create a balance? Is there something proactive we can do that would be less costly that would create more balance than just destroying our ability to use the fossil fuel society and which we benefit from?

Mr. HURRELL. Yes. I don't think any of us are interested in destroying the society and the technology that we benefit from. There is a certain level of climate change that we are committed to, as Dr. Hegerl spoke to.

Mr. SHIMKUS. I apologize. I only have little more time. Is there something that we can do other than capping carbon?

Mr. HURRELL. If you are referring to geo-engineering techniques, other things that we can do to help restore this balance, that is a topic of discussion that was very, very early my concern. With all of those approaches, there can be unintended consequences.

Mr. SHIMKUS. OK, I don't have time to go through all of the whole panel. Is there anybody that feels strongly on this debate?

Mr. OPPENHEIMER. Yes, I would just say that ultimately, we have to come to grips with the carbon problem, but that that could include efforts like the ones you heard of yesterday at carbon capture and storage or enhancing terrestrial sinks, or in other words, increasing biological production in forests. There are many ways to skin the cat, but in the end, carbon dioxide has to be limited.

Mr. SHIMKUS. I understand the report is not going to be made until May and I understand that, but it is in the releases of what people think is coming out. One would be that the hockey-stick aspect is not going to be part of this second report. Can you confirm or deny? And if is not, why?

Ms. HEGERL. The report has a section that talks the paleoclimatic perspective about our understanding of how temperatures in the last half-century compared to temperatures in the last I think 1,300 years. It is on page 10.

Mr. SHIMKUS. So you are telling me it is going to be included?

Mr. HEGERL. The discussion of temperature over the last millennium is definitely included.

Mr. SHIMKUS. So the hockey-stick graph and the proposals on that premise will be in this next report?

Mr. HEGERL. The report discusses temperature changes over the last millennium, and we understand a lot more about how temperature evolved over the last thousand years and also what caused many of these changes. Many of these changes were influenced by things——

Mr. SHIMKUS. OK, let me ask one last question, and I apologize again. I have have 5 seconds left.

I had dinner with a classmate of mine who is a NASA astronaut, and of course, he has been up twice now, and what he says, which is an interesting perspective, is when you are up in space and you look at the atmosphere, and it is very thin, we are our own little spaceship traveling through time. Does any of this global warming affect the destruction of atmosphere as we know it? We are talking about climate change and temperatures, but would it affect the breakup of atmosphere as we know it? Does anybody think it is part of that?

Mr. OPPENHEIMER. Are you asking whether it would affect the breakup?

Mr. SHIMKUS. Yes. I mean, is Earth at risk of just destroying and being a rock plummeting through space now?

Mr. OPPENHEIMER. Probably not.

Mr. SHIMKUS. Thank you.

I yield back, Mr. Chairman.

Mr. BOUCHER. Thank you, Mr. Shimkus.

That was certainly a reassuring answer.

Mr. OPPENHEIMER. With 90 percent confidence.

Mr. SHIMKUS. How many sigmas?

Mr. BOUCHER. Mr. Inslee is recognized for 8 minutes.

Mr. INSLEE. I defer.

Mr. BOUCHER. Mr. Inslee chooses to defer, and we will return to you at a later point. Mr. Burgess is recognized for 5 minutes.

Mr. BURGESS. Thank you, Mr. Chairman, and I thank the panel for a lively and thought-provoking discussing. Now, unlike the chairman who got a full summary, I only got two pages, so I don't want anyone to think I am intellectually constrained, only talking about two pages, but that is all I was given.

Now, Dr. Christy, can I ask you, I was most intrigued in your testimony. I didn't actually find in it in the written part that you submitted for us about the discussion that we just had with Mr. Markey about how life was brutal and short without adequate energy and how energy does make a difference and has made a difference to the quality of life that we all experience and has allowed us all to live longer and healthier lives. If we were willing to sacrifice that and said that is not something that is of any value, and we were wanted to go with metaphysical certainty to where Kyoto would have taken us and beyond, let us say we were to go to 60 percent below the 1990 levels, and say we could do that in the next couple of years. A hundred years from now, have we really helped things?

Mr. CHRISTY. Well, I don't think you would be reelected if you ran on that platform and actually did it. The economy would be almost totally destroyed if you are talking about 60 percent reduction in CO^2 emissions right now. The only way I see something like that happening is a massive nuclear power——

Mr. BURGESS. But if we did?

Mr. CHRISTY. It would be very, very tiny if just the United States was doing what you said.

Mr. BURGESS. Well, would we prevent a hurricane? Would we prevent a Katrina?

Mr. CHRISTY. No, Hurricane Katrina was a category 3 when it hit the coast.

Mr. BURGESS. Well, then I guess it leads the question, are we thinking about this problem in the correct way? If our goal is to eliminate carbon from the atmosphere in the form of carbon dioxide and the only way to go about it is to scale back the economy in ways that are really almost incomprehensible to me because of the costs of human suffering that would be involved, are we going about this the right way?

Mr. CHRISTY. Well, that I don't know. I don't sit in your seat and see all that you are doing.

Mr. BURGESS. Well, therein is part of the problem. And Chairman Barton alluded to it. And I mean under the summary for policymakers, I have got pages 9 and 10, and on page 9, which has the table 2 for policymakers, we have the likelihood of a trend occurring the last 20th century, second column, likelihood of a human contribution to an observed trend, and column 3, the likelihood of future trends based on projections of the 21st century. And on that middle column, I guess, is where I would like to concentrate, and if you would look at the last four areas that are studied. We are left with a designate of "more likely than not." And this includes heat waves, heavy precipitate, areas affected by drought, tropical cyclones increase, and increased incidences of extreme high sea levels. All of those things scored more likely than not. Have I got that right of what you have got on that table? Help me understand—and you already alluded to my reelection—to me more likely than not more mean 50.1 percent if it was a two-person race, but could be as low as, as we saw in Texas, 39 percent, if you have a four-person race. So what is the percent of more likely than not?

Mr. CHRISTY. As I understand it, it is 51 percent. Is that right?

Ms. HEGERL. It is greater than even odds, so 50 percent or greater.

Mr. BURGESS. Fifty percent, but that is only assuming that there are two eventualities. If there were a third in there, then that would reduce it even further, correct?

Ms. HEGERL. No, the four last instances are based on aspects of the climate system which we don't model very well, and which we cannot very confidently, at this point, attribute——

Mr. BURGESS. Mr. Chairman, I am going to run out of time. I guess what I would like to ask, if it is possible, and I may not have asked this very well, but I will try to submit this in writing to the entire panel. I would like to get your thoughts on that.

And just finally one last question—and I know this is true because I read it on a blog on the Internet—we are assuming that there is an absolute constant. I guess, Dr. Christy, you said in regards to global warming that solar radiation is the number one source for global warming. Is that a fair statement?

Mr. CHRISTY. It is the source of our energy that runs our system, yes.

Mr. BURGESS. Correct, well, assuming that none is coming from the Earth's core, and I don't know if that is still molten or not. It was when I when I was in high school. It may not be anymore. Of that solar radiation, is that an absolute constant?

Mr. CHRISTY. No, solar radiation varies, but what varies more would be, for example, the cover and constitutes in the atmosphere that would affect the Earth more.

Mr. BURGESS. But all of these assumptions, at least to my uninitiated eye, would mean that the solar contribution is an absolute constant, that it never changes.

Mr. OPPENHEIMER. No, that is not true. IPCC looks around carefully at that question, and we know very well what the solar variations have been over the last 30 years or so because we have satellites that stare at the sun all the time. And they have given us the indication that the sun's variation in the last 30 years when Earth has been warming a lot has been tiny. A tiny percentage, it can account for only a very, tiny percentage of the warming. And even looking back 250 years, changes in the sun could only account for less than 10 percent of the warming that has occurred.

Mr. BURGESS. Which brings me to the blog on the Internet and that apparently Mars too is afflicted with global warming and the reduction in size of their ice cap. Are humans responsible for the Mars problem as well?

Mr. OPPENHEIMER. Mars is afflicted with a greenhouse effect, just like we are, but we have an increase in greenhouse effect. And Mars probably doesn't.

Mr. BURGESS. Thank you, Mr. Chairman. You have been very indulgent.

Mr. BOUCHER. Thank you, Mr. Burgess. I totally neglected the time, but I am confident you used it well. Mr. Whitfield is recognized for 8 minutes.

Mr. WHITFIELD. Thank you, Mr. Chairman, and appreciate the panel being with us today. On this intergovernmental panel, the ICCP, whatever the initials are, how many scientists are on that panel? Anyone that knows the answer.

Ms. HEGERL. Hundreds of—depends on how you define the panel, the lead authors, or hundreds of lead authors. Do you remember that exact number?

Mr. HURRELL. There were 152 lead authors and 400 contributing authors to working group one, which deals with how the climate has been changing and the role of human activities in that.

Mr. WHITFIELD. My understanding that, of course, you have the lead authors for different segments of these reports. And I remember we had a hearing, an oversight investigation about a year ago, and there was some discussion about the impact of global warming on hurricanes and flooding and so forth. And some members of the IPCC that were making the big report had a press conference evidently at Harvard University, and one of them made the comment that global warming has an impact on the frequency of hurricanes. And as a result of that, the lead author of the hurricane section ended up resigning from the panel because he said this is more of a political statement than anything based on science. And he resigned from the panel. Are any of you familiar with that situation at all?

Ms. HEGERL. Sir, I don't think this refers to the IPCC but to the U.S. CCSP report, right?

Mr. CHRISTY. No, this was the IPCC, and he was not a lead author. He was a contributing author.

Ms. HEGERL. He was a contributing author?

Mr. WHITFIELD. He was a contributing——

Mr. CHRISTY. Yes, what was his name?

Mr. WHITFIELD. Chris Landsea.

Mr. CHRISTY. Yes.

Mr. WHITFIELD. Now, do any of you have any comment about that? I mean one of the issues about all of this global warming is that it seems to be becoming immersed in total politics. For example, there have been some IPCC reports that have said that anything below three degrees of warming in our climate, that developed countries will benefit economically and developing countries will not benefit economically. Are you all familiar with that statement?

Mr. OPPENHEIMER. Yes, I just want to point out that that is the arena that the second IPCC working group, which is not going to report until April deals with. And so there will be updates on that view, but they are not finalized yet so I can't discuss them.

Mr. WHITFIELD. But in 2001 or 2000, they did make that statement.

Mr. OPPENHEIMER. It is a statement. I can't remember the exact number. Up to a certain temperature, there could be benefits in certain areas, and the developing countries would more likely start to suffer before developed countries like the United States did.

Mr. WHITFIELD. When the Kyoto Protocol was being agreed to by some countries and not agreed to by other countries, there was a cry around the whole world about how catastrophic this would be. But 10 years ago in an article in "Geophysical Research Letters" they estimated that if every nation on Earth lived up to the United Nations Kyoto Protocol on global warming, it would prevent no more than .126 degrees Fahrenheit of warming every 50 years.

Mr. OPPENHEIMER. Yes, the Kyoto Protocol was viewed by those who signed it as only the first step, and it was recognized that much larger reductions would be needed if a significant difference was going to be made in global climate. And those could only have an effect over many, many decades. So while it is technically correct that the Kyoto Protocol would not have had much, if any, measurable effect on climate if that was all that was ever done, the expectation among the signatories was that wasn't the last step but only the first.

Mr. WHITFIELD. Yes, I think that as Members of Congress, not only in United States but around the world, it is helpful if we all could be less emotional on this issue because when the U.S. failed to sign this Kyoto Protocol, it sounded like the world was coming to an end. The U.S. was being so irresponsible. So I think if we can make this less sensational in any way possible, that we all benefit from that. And then a second part of this that certainly concerns all of us is the cost of global warming and the cost of preventing global warming. And I know at one time the IPCC, they looked at cost/benefit analysis, and then they reach a point where they said we are not going to consider cost at all. And then you had some, I guess, people who developed some models to look at cost, one referred to as Dice, now, tell me about Dice.

Mr. OPPENHEIMER. Dice is an economic model which attempts to look at the balance between costs of reducing emissions and the damages from not reducing emissions and seek what the optimum balance is over the course of the next century.

Mr. WHITFIELD. Now, why would the IPCC not be involved in looking at that as well?

Mr. OPPENHEIMER. Well, in fact they have been, and again the report on economic consequences won't be out until May. And I am not involved with it, so I can't speak about it. But the last IPCC report, they did publish different ways to look at that balance, and a crude way to look at it is if the atmosphere, the cost of restricting warming to remain near those lower curves that you showed before, would be several percent of global GDP cumulative over the next 50 years. That is not several percent per year. That is several percent cumulative over 50 years, and the cost of the known damages were roughly the same; that is, excluding things like a large rise in sea level due to the loss of the ice sheets. So many economists said well, if those two things are in balance, we ought to start doing something about it. And that is what the Dice model shows, that a current investment makes sense.

Mr. WHITFIELD. OK.

Mr. BOUCHER. The time of the gentleman has expired.

Mr. WHITFIELD. Thank you.

Mr. BOUCHER. Mr. Inslee for 8 minutes.

Mr. INSLEE. Thank you. Just kind of a bonehead question. CO^2 warms the planet. What would the mean temperatures of the planet be if there were no CO^2 in the atmosphere? Dr. Hurrell, do you want to start on that? Just, by an order of 300 percent.

Mr. HURRELL. Yes, it is like a 33-degree Celsius difference, I believe, with no greenhouse gases.

Mr. INSLEE. So no——

Mr. HURRELL. Fifty-one?

Mr. HASTERT. Are we talking about——

Mr. HURRELL. I was talking about the total greenhouse——

Mr. HASTERT. He just asked about CO^2.

Mr. INSLEE. Yes, let us start with greenhouse gases. Roughly how much colder would it be?

Mr. HURRELL. Total greenhouse gas?

Mr. INSLEE. Yes, total greenhouse gas.

Mr. HURRELL. Thirty-two degrees.

Mr. INSLEE. OK, how about carbon dioxide any ideas at all? Just don't know.

Mr. HASTERT. Can I ask it would be 32 degrees colder?

Mr. HURRELL. Yes, the planet is warmer by 32 degrees Celsius because of the greenhouse gas effect. That includes the natural greenhouse gas effect from water vapor as well as——

Mr. HASTERT. And so if we are at zero Celsius right now, just say we are, we would be 32 degrees Celsius below the point we are at now?

Mr. HURRELL. Right. Well, go ahead.

Ms. HEGERL. Well, there wouldn't be an atmosphere so we would have no weather.

Mr. INSLEE. So the reason that concerns me is that we are going to be about twice pre-industrial levels of at least one major greenhouse gas, CO^2, in the next century or so unless this Congress pulls its head out of the sand and does something. So that means if you go down with somewhere in the neighborhood of 30 Celsius, there is going to be big impacts in the world if we don't do something. And that may not be a one-to-one correlation, but I am just telling you how one congressman looks at that concern about how significant greenhouses gases are to the climatic systems of the Earth. We are going to be at double the levels that we had in pre-industrial times. Now, I am really glad that Dr. Christy came here because I——

Mr. BARTON. Would the gentleman yield?

Mr. INSLEE. If you will give me some more time.

Mr. BARTON. Your questions are very important, and you are one of the most knowledgeable congressmen on this issue. I mean you really are. You were very patient in the minority, and you have every right to be a lot more impatient in the majority. But I want it to be clear that this 32-degree Celsius change, most of that is natural. It is not manmade CO^2. It is water vapor that 95 percent is natural water vapor.

Mr. INSLEE. I understand that, and I want to come back to Mr. Barton's comment, which I think is probably accurate, that only about 5 percent of the CO^2 emitted in the atmosphere is from anthropomorphic sources. Now, the reason that statistic is cited because it sounds like a diminimus amount.

However, that is a 5 percent unnatural, if you will, increase to the net zero that occurred in pre-industrial times. That means it is like eating doughnuts for the next 20 years. If we all ate enough to gain 5 pounds a year, enough doughnuts, which I will call the unnatural part of our diet in our atmosphere, we are adding carbon dioxide doughnuts. And every year it goes up 5 pounds, or 5 percent. Now, that means in 20 years, I would weigh 400 pounds. So that 5 pounds didn't sound like much, but what I am pointing out here is we are heading to a level of double the CO^2. And CO^2, if we look backwards, when you double something, it has a major impact. We know we could be in a frozen planet if we had half as much CO^2, and if we have double the amount CO^2, it is very concerning. That is my reaction to this.

Now, I want to ask Dr. Christy a question. I am glad you came because listening to your testimony, what I am hearing you saying is yes, carbon dioxide is playing a role. I don't think you said the majority role, but some of the role of climate change. And you talked about your work that I respect as a missionary in Africa, and what I take from you is you sort of assume that if we do something about CO^2, we are going to all go back and live like the people do in Africa in that terrible poverty that you worked diligently to aid.

But I want to quote a group called Christian Aid. It is an evangelical missionary and development organization. They have worked in Africa for 50 years, and here is what they say. "It is vulnerable people in poor countries that are affected first and most seriously. Climate change is the most significant single threat to development. It could undo decades of progress in fighting poverty."

Christian Aid believes that a new global agreement must be reached to cut emissions and provide help to poor people who are on the receiving end of global warming. Any such agreement must be based on scientific, not political, targets.

Now, what I understand your sort of working hypothesis, Dr. Christy, is for us to do something about this, we are going to have to go back and live in the stone ages. And the reason is that you just don't believe that mankind has been given an intellectual capability sufficient enough by the creator to develop technologies to deal with this that don't put CO^2 in the atmosphere. Now, that is the working assumption that sort of underpins your testimony. So I want to ask you do you about the Nanosolar Corporation out in California?

Mr. CHRISTY. I was delighted to hear that you were on the subcommittee.

Mr. INSLEE. Just answer the question. Do you know about Nanosolar Corporation?

Mr. CHRISTY. I probably read about it, but I could not recall anything.

Mr. INSLEE. Do you know about the A123 Battery Company?

Mr. CHRISTY. No, I don't.

Mr. INSLEE. OK, just so you will know, they are a company that has developed a lithium ion battery that could potentially run a car for 40 miles with zero CO^2. Do you know about the general compression company?

Mr. CHRISTY. Americans are innovative, and they can provide ways to create energy that doesn't use carbon dioxide. And I am all for it if I don't have to pay twice as much.

Mr. INSLEE. Right, so the general compression technology, basically they have a way of compressing air to create a battery system to use compressed air to become essentially a battery for wind turbine technology that they believe could increase by a factor of two the efficiency of a wind turbine system because it can make an intermittent power to be stable, base load power. What percentage increase of technology do you believe Americans can create in the next 20 years, per year, as an increase, let us say, in efficiency? What number do you believe we can increase per year and not reduce our economic growth?

Mr. CHRISTY. I want to respond to that Christian missionary thing. I am a Christian missionary and a climate scientist. So I can talk about both those sides. I don't think those folks can. The problem in Africa is governance.

Mr. INSLEE. Well, let me tell you there is another problem in Africa.

Mr. CHRISTY. The question about if I were just to guess and that is all it would be would be a guess, is that to get those systems into the current energy distribution and generation system would take decades from what I understand the situation is now, except for nuclear.

Mr. INSLEE. And I appreciate that comment, and I think to some degree it is accurate. But let me suggest that the fact that it will take decades for us to rebuild our economy, to be largely carbon neutral, is not an argument for delay. It is an argument for hastening action. The fact that it is going to take us some time and that there are some uncertainties about global warming and that there are uncertainties about what technologies we are going to use, isn't that an argument to get started this year in Congress, rather than an argument to wait?

Mr. CHRISTY. When you say get started, that is where I worry about the people in Alabama who are struggling to pay their energy bills now.

Mr. INSLEE. I understand that, and if the people of Alabama would adopt some of the things that we have done in other States like California, we could reduce our energy by 50 percent. The people in Alabama have increased their per capita consumption, and I don't know Alabama for sure, but nationally, by 50 percent over the last 20 years. The people in California who are still enjoying hot tubs and they have still got a booming economy have had a flat rate of growth in energy per capita in the last 20 years because they have responded to this. So I am glad you came. Thank you very much.

Mr. CHRISTY. Thank you.

Mr. BOUCHER. Thank you, Mr. Inslee. Mr. Sullivan is recognized for 5 minutes.

Mr. SULLIVAN. Thank you, Mr. Chairman, and this is complicated, climate change, global warming. I am trying to learn a lot about it. I don't know much about it, and maybe some of you could help me with some of these things. I heard today that Chairman Markey said that—or I think Mr. Oppenheimer might have said that sea level would go up 40 feet, and that scares me. A lot of people would probably die if that happened. Also, I think Mrs. Hegerl had said that—you were talking about some modeling and some temperatures from 1,300 years ago until now, and that there has been some dramatic change. I like using dynamic economy models here for tax relief, and a lot of people don't like those. Say that my modeling is wrong, and I think there is always room for error in these modelings. Let us talk about 1,300 years ago, Mrs. Hegerl. What kind of meteorologists were on the planet and what kind of thermometers did they use? And where were the weather stations? Let us just say 500 years ago, what kind of thermometers? I am just curious.

Ms. HEGERL. To reconstruct temperatures over the last millennium, we use proxy data that, for example, reading that approximately respond to changes in temperature. So you can reconstruct with uncertainties temperatures over the past based on indicators that follow the climate——

Mr. SULLIVAN. With uncertainty?

Ms. HEGERL. With uncertainty. On the other hand, when we try to understand what happened in the last millennium, we also have indicators of what influenced climate, and those are virtually independent. For example, entries in ice course in Greenland and Antarctica, that indicated what kind of corruption and the correspondence between those two things, which are virtually independent really, gives us some confidence that we can understand to what extent what happened in the past and also that we are not completely blowing reconstructing the past.

Mr. SULLIVAN. And we talked about this naturally occurring phenomenon of the water affecting the environment, and I believe 96 percent is natural. Is there anything we can do to change that?

Ms. HEGERL. When we increase CO^2 in the atmosphere, you have a bank with water vapors. The water vapor increases as we increase CO^2. It is a positive feedback, so when we exchange——

Mr. SULLIVAN. When you say that is climate models.

Ms. HEGERL. It is also been observed. Both the vapor increases have been observed.

Mr. SULLIVAN. And so you are saying that you can do these models with absolute certainty of temperatures?

Ms. HEGERL. No.

Mr. SULLIVAN. That is what you said earlier.

Ms. HEGERL. No, I am not saying we are doing with certainty.

Mr. SULLIVAN. That is neat if you can. I don't know much about science. I didn't know that that could happen.

Ms. HEGERL. No, but the IPCC has predicted through to temperatures since 1990, and we have done relatively well predicting what would happen in the 15 years since the process started. It has been warming, and it is within the range that we predicted.

Mr. SULLIVAN. And would you agree, any of you, that this is pretty complicated stuff, and we need to move cautiously when we make major decisions? Would most of you agree with that? The Speaker wants us to have a bill by June to fix all this. Do you think that that is kind of a rush timeframe to get this done, that we should look at this and examine it very carefully?

Mr. OPPENHEIMER. I think that is your decision, not ours.

Mr. SULLIVAN. But wouldn't you agree?

Mr. OPPENHEIMER. I think the problem should be looked at carefully, but we have a very large body of knowledge. It has been accumulating since 1896 on this problem. There are reports stacked that thick—I think it is probably possible with reason by June——

Mr. SULLIVAN. Well, Doctor, we can fix this tomorrow then?

Mr. OPPENHEIMER. You could get advice on how to fix it, but it wouldn't be completely fixed for many decades, if then.

Mr. SULLIVAN. Well, with all the modeling that you do, do you do any modeling of how this will affect the economy and——

Mr. OPPENHEIMER. It has been done.

Mr. SULLIVAN. And would it be detrimental to the economy?

Mr. OPPENHEIMER. There are different views. It is not going to happen, but if the U.S. had implemented the Kyoto Protocol, the estimates were about a 1 percent decrease in total GDP cumulative over the 10 years of implementation, according to the midrange of the models. In other words, about a tenth of a percent per year.

Mr. SULLIVAN. OK. Well, Dr. Christy, is it correct that you have constructed observational data sets?

Mr. CHRISTY. Yes, we build them from scratch.

Mr. SULLIVAN. Can you elaborate on what is involved in the observational work you do?

Mr. CHRISTY. We do everything from going to libraries and getting the paper records, dusting them off and digitizing them, to getting the digital counts from satellites to create upper air data sets. I mean we start from scratch, and very few people in the world, by the way, actually do that.

Mr. SULLIVAN. That is good. Also I guess I am curious, all the panelists, how many of you have put together observational databases from scratch? What type of actual climate observational work, not climate modeling, do you do?

Mr. HURRELL. I have not put together an observational data set from scratch. I am, however, a climate diagnostician. I do not build models. I primarily have analyzed observational data sets my entire career.

Mr. SULLIVAN. So you haven't done it?

Mr. BOUCHER. Thank you, Dr. Hurrell. The gentleman's time has expired. Mr. Walden for 5 minutes.

Mr. WALDEN. Thank you, Mr. Chairman. And I appreciate the testimony of the witnesses, and my apologies for having to kind of come and go. It is that season here on the hill where everybody is in town, and we are generally triple booked. Dr. Christy, it appears that models get the global average temperature simulations to match some global average surface temperature observations. But do models get the patterns of warming that has been observed correctly?

Mr. CHRISTY. In the data sets we construct, the answer is no, and it is a little bit misconception to say that they match even the global temperature because remember modelers already know the answer ahead of time. So matching that was not that great of a feat when it was designed to match the last 100 years of climate records.

Mr. WALDEN. Does that mean then that they somehow manipulate the data to get to the temperatures that were supplied?

Mr. CHRISTY. No, they don't manipulate the data, but there is a level of what we call tuning that occurs to make sure that all the things balance right so that the temperature matches what was observed in the global average sense.

Mr. WALDEN. Do they get the tropical patterns of warming or the observations of warming at different altitudes?

Mr. CHRISTY. Not that we have found, no.

Mr. WALDEN. And what is the effect of that on our policymaking here?

Mr. CHRISTY. It would be just to raise great caution about using them as predictive tools.

Mr. WALDEN. OK.

Mr. HURRELL. Are we allowed to respond?

Ms. HEGERL. Yes, I would like to make one comment. The ocean heat content data set came out in 2001, so by the time many more tools were used to analyze it were built and run, the data did show that the ocean content gained heat. And the pattern with which it gained it has not been known to the modelers. So this is one great example of a completely independent data set that wasn't——

Mr. HURRELL. I would just like to on the record state that climate models are put together. They are very complex tools, trying to represent the complexity of the climate system. But individual processes are modeled based on our best scientific understanding. That entire set of processes are then put in models, and the models are allowed to freely integrate in time. So the very impressive match on global and continental and ocean basin scales of today's climate models in replicating historical record are a very powerful statement that the models have reached a point where they are very, very useful tools. And they give us much increased confidence in future predictions.

Mr. WALDEN. All right, then what should we make of the science report this summer that the upper surface of the ocean cooled substantially between 2003 and 2005, which cut by about one-fifth of long-term upper ocean heat gain between 1955 and 2003? It doesn't seem to square with the IPCC summary telling us, or what the models portray, doesn't it?

Ms. HEGERL. Variations over a short time scale are very difficult to interpret, and it is much more helpful to look at the longer timeframes. And those variations are interesting, and for us, as scientists, fascinating. But I would warn of trying to extrapolate them for a longer time.

Mr. WALDEN. Well, do you see short-term variations on some of the glaciers and all too? I am thinking in the Northwest last summer, we were told in Oregon the glaciers had receded by 50 percent. And about three weeks ago, they came back with revised forecast that it was actually 35 percent.

Mr. OPPENHEIMER. One does see short-term variations in glaciers, and they are of a surprising degree.

Mr. WALDEN. Right.

Mr. OPPENHEIMER. It turns out that ice could move much faster than we thought. It can accelerate, and it can stop much faster than we thought.

And that is, by the way, one of the reasons we don't have a lot of confidence in the models. They don't predict such changes. Those are the ice sheet models. That is distinct from the atmosphere climate models.

Mr. WALDEN. I understand, and I am not necessarily making the argument the Earth isn't getting warmer. I mean I believe we have had thermometers, and you have got predictive models, and they may be up and down and all that. My question though is in the limited data that I have been trying to get up to speed on, it appears this has been an accumulation during the Industrial Age. It has been close to 100 years that we have been, if you follow the theory, we have been putting carbon and other pollutants into the atmosphere that has caused this to occur. I have also read that it could be 100 years if we got back to equilibrium before you might see a substantial temperature change downward.

Mr. OPPENHEIMER. I think a simple way—a cartoon of the situation is if you stopped all emissions today, it would take many decades, probably about two centuries, for carbon dioxide to return to the level of around 300 parts per million.

Mr. WALDEN. And if you get much below that, am I not correct that we go back into an ice age? Weren't we in an ice age in the 50 to 100 parts per million?

Mr. OPPENHEIMER. No. The last ice age came to an end about 10,000 years ago. And since then, climate has had——

Mr. WALDEN. No, my question is what was the carbon level in the atmosphere during the Ice Age?

Mr. OPPENHEIMER. About 200 parts per million.

Mr. WALDEN. That is what I was saying. If you got down to 50 to 100, I had it lower than what you are saying.

Mr. OPPENHEIMER. Right, but that is not going to happen.

Mr. WALDEN. I didn't ask that. No, that wasn't what I was saying. There is a point where you don't want to eliminate all carbon out of the atmosphere or you have cooling right? Again that was the issue in the 1970's. I remember some of those stories, The Coming Ice Age, and all that in "Time" magazine.

Mr. OPPENHEIMER. The likelihood is we are never even going to get back to the pre-industrial level of 280 parts per millions. It is simply not going to happen because we put so much carbon dioxide in the atmosphere. If we stopped our emissions, it would gradually fall out, but we are stuck with some of that carbon dioxide for 1,000 years or more.

Mr. WALDEN. Some of it lives a very long time.

Mr. OPPENHEIMER. Correct.

Mr. BOUCHER. The gentleman's time has expired.

Mr. WALDEN. Thank you, Mr. Chairman, for your indulgence.

Mr. BOUCHER. Mr. Barton has asked for the opportunity to propound some additional questions, and at this time, I am going to recognize him for an additional 5 minutes of questions.

Mr. BARTON. I am going to try to be as quick as possible, Mr. Chairman. Thank you for your courtesy. What is the largest concentration of CO^2 in the atmosphere ever as far as we know if you go back to prehistoric times?

Mr. OPPENHEIMER. Ever?

Mr. BARTON. Ever.

Mr. OPPENHEIMER. Ever, there were times in Earth's history where there was much more carbon dioxide than today, but in the time——

Mr. BARTON. Well, I mean just give me a number. I mean I am told that plants are genetically best able to reproduce themselves and thrive at 1,000 parts per million of carbon in the atmosphere. Is that a true statement or a non-true statement?

Mr. OPPENHEIMER. We don't actually have a good picture because those levels of carbon dioxide haven't recurred for millions and millions of years.

Mr. BARTON. But isn't it a fact that in the past we have evidence or we at least have theories that carbon has been much higher concentration than 380 parts per million?

Mr. OPPENHEIMER. Yes, and Earth was much, much, much warmer.

Mr. BARTON. OK, and even you would admit those weren't driven by manmade emissions?

Mr. OPPENHEIMER. Even I would admit that that was natural, but it occurred very slowly over millions of years.

Mr. BARTON. Well, but I mean the point is that we are taking as a base period 1750 or 1850, which we are in what we at one time called the Little Ice Age, and since that time, the temperature has been going up, which you would assume, if you are coming out of an ice age, it would be going up?

Mr. OPPENHEIMER. Excuse me. It was not an ice age. It was a small decrease in temperature mostly in the North Atlantic Basin.

Mr. BARTON. It was in popular literature until recently it has been called the Little Ice Age.

Mr. OPPENHEIMER. Right, but it had some effects in the North Atlantic Basin and maybe some other places. An ice age means 1,000 feet of ice reaching down to New York.

Mr. BARTON. Well, we have had higher concentrations of CO^2 and higher concentrations of carbon than what we have today.

Mr. OPPENHEIMER. Right.

Mr. BARTON. That is a true statement.

Mr. OPPENHEIMER. Sure, and what we perhaps will do over this century is return Earth's temperature to levels that were near what they were several million years ago.

Mr. BARTON. I want to ask Dr. Christy a question. Are clouds critical to how warm or cold the Earth is?

Mr. CHRISTY. They are critical.

Mr. BARTON. How well do we understand the formation of clouds?

Mr. CHRISTY. Not well at all.

Mr. BARTON. How do we account for clouds in these models that the scientists have been talking about?

Mr. CHRISTY. Well, the grid squares on which calculations are done are fairly large, a few hundred kilometers. And so clouds cannot be represented in that with a single point number. So they are, in a sense, statistically represented in terms of their effects on the radiation and so on.

Mr. BARTON. I am told that there are about 20 models that portray themselves as being able to model climate in the atmosphere and that none of these models accurately account for clouds. Is that a true statement or a non-true statement?

Mr. CHRISTY. Well, it hinges on accurately, and from my point of view, I would say that is true.

Mr. BARTON. Dr. Hurrell, would you agree or disagree with that last statement?

Mr. HURRELL. I agree the clouds are a major shortcoming of today's climate models.

Mr. BARTON. OK, if you were a policymaker, given the uncertainty just in that one variable, how many millions of jobs would you put at risk for political correctness? It is a fair question. That is what we are being asked to do by the 1st of June.

Mr. HURRELL. I resent the notion that the greenhouse effect as a problem involves political correctness. It is, in first order, a scientific issue. Whether it is worth doing anything about and how much is indeed your own decision.

Mr. BARTON. Well, your own testimony earlier, Doctor, was that if we totally eliminated manmade CO^2 emissions, it could be several centuries before we saw any change.

Mr. HURRELL. No, I didn't say that. I said it would be several centuries before carbon dioxide would return even close to pre-industrial levels. That is something quite different.

We could have a substantial change on future climate by limiting emissions, and in addition, it needn't bankrupt the economy. That is a false comparison, as the progress in California has shown. It was referred to by the Member from Washington.

Mr. BARTON. My time is about to expire. Let me ask one last question.

Mr. HURRELL. Sure.

Mr. BARTON. Your radiative forcing components in this summary shows that there is some manmade forcing components that are negative. As a policy option, should we consider doing some of the negative things that would balance the positive?

Mr. HURRELL. If you want people to be breathing dirtier air, sure, go ahead. But I don't think people want to solve one environmental problem on the back of another.

Mr. BARTON. OK, I thank the Chair's courtesy, and I am going to have some written questions for this group.

Mr. BOUCHER. Well, without objection, written questions may be submitted to this panel. And when they are, we would appreciate your expeditious response. Mr. Hastert.

Mr. HASTERT. I just want to thank the panel. This is what it is supposed to be, a learning experience. One of the things we have learned is that there is not a lot of exactness there. There is a lot of maybe and ifs and clouds do this and maybe not and ice sheets, and I appreciate the frankness and candidness of this panel. It has been very helpful. Appreciate everybody being here today.

Mr. BOUCHER. And let me second that sentiment. I very much appreciate your willingness to spend time with us today. It has been a rather long period of time, and we thank you for your answers. Mr. Burgess, do you have a comment you would like to make?

Mr. BURGESS. Yes, I do have a comment. We have heard some rather intriguing science and certainly the level of uncertainty around some of these issues that were discussed today just leads me to believe that the timeline that we are on to produce a legislative product by June or July is absolutely untenable. And I hope the chairman will communicate with his leadership about the hearing that we have had today and the fact that it was well attended, at least on our side. There is a genuine willingness there to learn. We are going to need more time to develop a legislative product that does not put our economy at risk and still serves the needs of generations to come.

Mr. BOUCHER. Thank you, Mr. Burgess. And let me assure you that we are having in-depth discussions on the majority side about the schedule.

Mr. BURGESS. I will be glad to show up and help you with those discussions.

Mr. BOUCHER. Thank you. I might call on you to do that. Well, with those comments, we thank our panel, and this hearing is adjourned.

[Whereupon, at 1:40 p.m., the subcommittee was adjourned.]

[Material submitted for inclusion in the record follows:]

Climate Change: Are Greenhouse Gas Emissions from Human Activities Contributing to a Warming of the Planet?

Roni Avissar, Civil and Environmental Engineering, Duke University (avissar@duke.edu)

Testimony Summary

The Earth system is still not understood well enough to precisely answer the question: "How do you expect future global temperatures to be affected by *greenhouse gas emissions* from human activity?" Simulations performed with state-of-the-art regional climate models add a perspective on multi-scale interactions involved in the Earth system that are not simulated in Atmosphere-Ocean General Circulation Models (AOGCMs) and, therefore, have not been accounted for in studies performed with these models. These simulations lead to significantly different results and conclusions on the behavior of the Earth system. Human activity has an impact on the Earth system that is broader than greenhouse gas emissions. For example, land-cover changes due to land use play a significant role in climate change, through feedback on ecological and hydroclimatological processes (including, among others, clouds, precipitation, fires, carbon and aerosols). Whether land use enhances or mitigates the effects of greenhouse gas emissions, and at which pace the various human activities and corresponding responses of the modified environment occur, remains to be clarified. A new generation of climate models capable of simulating such multi-scale processes and feedback is required to answer these questions more precisely. Nevertheless, there is conclusive observational evidence for global temperature and sea level rise, and ice caps and snow cover shrinkage. These phenomena are well correlated with human activity, broadly defined. Thus, the issue for scientific debate is the *relative* contribution of individual human activities, which is needed to anticipate the impact of future emissions, not their overall contribution to climate change, which according to the recent IPCC report has now been established with a high level of confidence.

Introduction:

Climate models are essential tools to study the various processes that take place in the Earth system. Yet, they are not accurate enough to precisely *assess* the impacts of greenhouse gases emissions (as a separate component of the various human activities) on our future climate. As summarized in the National Research Council report on "Radiative Forcing of Climate Change" (NRC, 2005) "*...there are major gaps in understanding of the other forcings, as well as the link between forcings and climate response. Error bars remain large for current estimates of radiative forcing by ozone, and are even larger for estimates of radiative forcing by aerosols. Nonradiative forcings are even less well understood...*"

Simulations produced with AOGCMs miss significant processes that drive the climate response in somewhat unexpected ways. As an example to demonstrate this issue, simulations of deforestation of the Amazon Basin are produced with a state-of-the-art regional climate model, namely the Regional Atmospheric Modeling System (RAMS) developed at Colorado State University. By using a much better resolution than that typically adopted in AOGCMs, land-atmosphere interactions (including clouds and precipitation) are simulated more accurately with regional models. They are compared to the simulations produced with the NASA Goddard Institute for Space Studies Model II, one of the well-accepted GCMs.

Regional *vs* Global Modeling:

Soares Filho et al. (2004)[1] have produced scenarios of land-cover change in the Amazon Basin for the next fifty years based on socio-economic development anticipated in that region. Figure 1 illustrates their predicted land-cover map for 2050.

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[1] Soares-Filho, B., A. Alencar, D. Nepstad, G. Cerqueira, M. D. V. Diaz, S. Rivero, L. Solorzano, and E. Voll, 2004. Simulating the response of land-cover changes to road paving and governance along a major Amazon highway: The Santarem-Cuiaba corridor. *Global Change Biology*, **10**, 745-764.

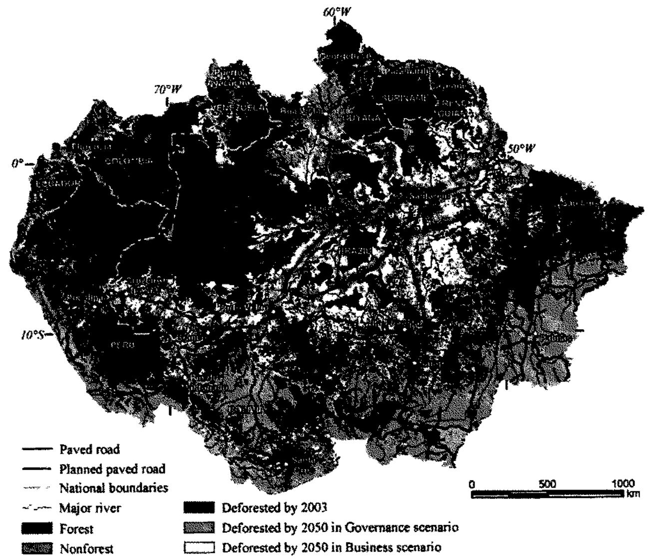

Figure 1: *Land-use map of the Amazon Basin based on socio-economic development of that region by 2050.*

Figure 2 shows the January-February mean rainfall observed in the Amazon Basin for the period 1970-2000. One can notice that year 1997 was particularly wet, 1998 (which was an El Nino year) was particularly dry, and 1999 and 2000 received an amount of rainfall similar to the 30-year average.

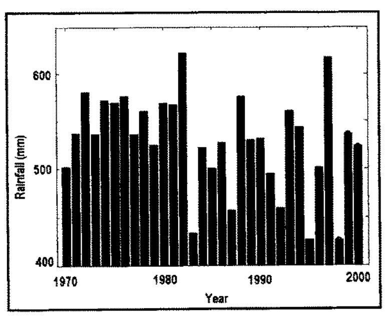

Figure 2: *January-February mean rainfall in the Amazon Basin for the period 1970-2000.*

Using the meteorological conditions of these four years as a representative sequence of weather conditions in this region, together with the scenarios of land-cover change produced by Soares Filho et al. for 2030 and 2050, we studied the hydroclimatological impacts of deforestation in the Basin with RAMS. We also produced a "control" simulation using the current land-cover map of the region, and a "total deforestation" case that could possibly happen by the end of the century at the current pace of deforestation in that region.

Figure 3 illustrates the change of precipitation obtained with RAMS for the 2050 land-cover scenario. Unlike the results obtained with a typical GCM, it is interesting to note that the heavily deforested eastern part of the basin experiences an increase while the western part of the basin sees a reduction of precipitation. This is particularly noticeable during El Nino events (not showed here). Considering the entire basin (Figure 4), the GISS GCM simulates a stronger reduction of precipitation due to heavy deforestation. During the wet year of 1997 (and to some extent in 1999 and 2000), deforestation has very little impact on precipitation. However, the *type* of precipitation changes from the "green ocean" that is obtained with current land-cover conditions to convective rainfall when the region is deforested. This significantly alters the ground radiative balance.

Comment:

The precipitation shift and cloud structure simulated with RAMS are not represented by the GCM. They have a significant impact on the radiative forcing, which is typically used as a criterion to evaluate the human impacts on climate. Furthermore, the ecosystem feedback to the climate through more frequent fires that are likely to be triggered in the western part of the basin as a result of intensified droughts produced by the precipitation shift is not represented in these models. The release of aerosols by the fires and their direct and indirect impact on the radiative forcing is not well understood. The ecosystem response under the joint influence of precipitation shift and increased carbon dioxide is not known, let alone represented in these models. Yet preliminary results indicate that increased carbon dioxide tends to intensify rainfall in that region, mitigating the effects of deforestation. Therefore, better models accounting for such processes are needed.

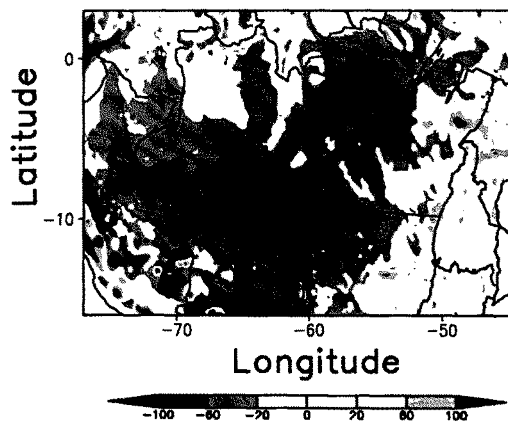

Figure 3: *Rainfall anomaly (mm) relative to the "control" simulation for the land-use scenario of 2050.*

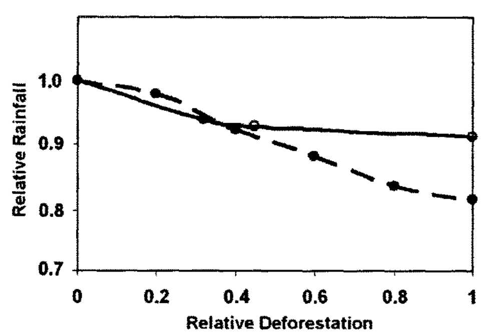

Figure 4: *Relative rainfall (compared to the "control" case) as affected by relative deforestation simulated with RAMS (solid line) and with the GISS GCM (dashed line).*

House Committee on Energy and Commerce
Subcommittee on Energy and Air Quality

Written Testimony of John R. Christy, PhD
University of Alabama in Huntsville
7 March 2007

Chairman Boucher, Ranking Member Hastert and committee members, I am John Christy, professor of Atmospheric Science and Director of the Earth System Science Center at the University of Alabama in Huntsville. I am also Alabama's State Climatologist. I served as a Lead Author of the IPCC 2001 report and as a Contributing Author of the 2007 report.

SUMMARY

I will be reporting today on research that has appeared recently or that will be published shortly.

In the following testimony I will first describe how a carefully reconstructed time series of temperatures in the Central Valley of California indicate that changes since 1910 are more consistent with the impacts of land-use changes than the effects currently expected from the enhanced greenhouse theory. This and other research points to the need for a better temperature index than what is used now over land: *daytime* temperatures, rather than the *average daily* temperatures (used now), are more directly representative of the layer in the atmosphere affected by greenhouse gases. Secondly, I will describe results from two papers which examine our knowledge of atmospheric temperatures as they relate to the surface. The results point to a more modest atmospheric warming than anticipated from our current understanding of the enhanced greenhouse theory. Further, I argue for an independent program with significant funding to evaluate climate model simulations and projections with a healthy, objective eye.

I then include comments on my view of the unfortunate and incorrect attempt to demonize energy and its by-products. Without energy, life is brutal and short. The option of ethanol as a substitute for petroleum is addressed pointing out that though there are serious concerns, there is indeed a way to achieve a significant increase in production in the U.S. if that is the course the country deems necessary.

The meaning of my climate research for policy makers is two-fold. First, it is apparent that we have little skill at reproducing and predicting changes on regional scales of the size up to a region like conterminous U.S. Secondly, it is therefore far more difficult to predict the climate effect of a particular policy aimed at altering current emissions of greenhouse gases (by small amounts) and thus somehow "hold back global warming". In other words, we are unable with any confidence to predict or detect climate outcomes from Kyoto-like policy options, especially on the scale where our citizens live.

[Many of the statements below will use the terminology "consistent with" rather than "proof of". This is the way science works in the field of climate because we basically cannot give "proof" of the type found in laboratory experimentation.]

CENTRAL CALIFORNIA TEMPERATURES

Last year I and 3 coauthors published a paper on temperature trends in Central California since 1910 (Christy et al. 2006). This was actually a follow-on of work I did as a teenager growing up in the San Joaquin Valley some 40 years ago when all I had was a pencil, graph paper, a slide rule and a fascination with climate. In this new work, sponsored by the National Science Foundation, we set out to collect all available information on surface temperatures in the Valley and nearby Sierra Nevada foothills and mountains and then develop a means to generate temperature trends with defined levels of confidence.

What drew my attention to this problem was the apparent rapid rise in nighttime temperatures in the Valley, temperatures that appeared to be much above those I remember recording as a teenager. We eventually produced a dataset with many observations never before utilized (we performed the manual digitization of many of those records.) In addition, we examined all of the ancillary information to document changes experienced by stations that could affect the overall trends. This involved reading and digitizing over 1600 pages of information about the stations and instruments. This has not been done before in California.

We then developed a method which takes into account the various events that affected each station, i.e. a move, a change of instruments, a change in procedure, etc. We discovered that on average, a station experienced about 6 events that could produce a change in the surface temperature. After adjusting for these changes, we combined the stations in the Valley to see what went on the last 100 years and did the same for the Sierras as a control experiment. Our work uses literally 10 times the amount of data of previous attempts at creating such temperature records.

We discovered that indeed the nighttime temperatures in the 18 Valley stations were warming rapidly, about 6°F in summer and fall, while the same daytime temperatures fell about 3°F. This is consistent with the effects of urbanization and the massive growth in irrigation in the Valley.

The real surprise was the composite temperature record of the 23 stations in the central Sierra foothills and mountains. Here, there was no change in temperature. Irrigation and urbanization have not affected the foothills and mountains to any large extent. Evidently, nothing else had influenced the Sierra temperatures either.

These results did not match the results given by climate models specifically downscaled for California where the Sierra's were expected to have warmed more than the Valley over this period (e.g. Snyder et al. 2002).

Because these results were provocative, we performed four different means of determining the error characteristics of these trends and determined that nighttime warming in the Valley was indeed significant but that changes in the Sierras, either day or night, were not. Models suggest that the Sierra's are the place where clear impacts of greenhouse warming should be found, but the records we produced did not agree with that hypothesis. For policymakers in California this result is revealing. It suggests that to "do something" about warming in central California means removing agricultural and urban development rather than reducing greenhouse gas emissions.

[Note: as a follow-up to Christy (2002) on Alabama temperature trends, we examined the output from 10 climate models. All models showed a warming trend for 1900 to 2000 in the SE U.S. However, observations show a cooling trend (common throughout the SE U.S.) Additionally, Kunkel et al. 2006 perform a similar analysis for the central U.S. where temperatures have not experience a warming trend while model simulations of the same period do. Kunkel et al. identified this feature in the central U.S. as a "warming hole".]

The bottom line here is that models can have serious shortcomings when reproducing the type of regional changes that have occurred. This also implies that they would be ineffective at projecting future regional changes with confidence, especially as a test of the effectiveness for specific policies. In other words it will be almost impossible to say with high confidence that a specific policy will have a predictable or measurable impact on climate.

We are nearing the end of an extensive study of surface temperatures in East Africa, a place I had lived and monitored the weather in the mid-1970s. Our preliminary results are similar to those from Central California in that daytime temperatures are not changing at all, while nighttime temperatures appear to be rising. This particular area is of great interest because two of Africa's ice-capped mountains, Mt. Kilimanjaro and Mt. Kenya, reside in this region. There is clearly no doubt that these East African ice fields are shrinking. However if general warming is the reason, it should be due to the rise of daytime temperatures, because nighttime temperatures are well below freezing already. However, we find little if any warming in daytime temperatures, suggesting these ice fields are disappearing for reasons unrelated to a general warming … perhaps to decreasing cloudiness and precipitation.

A soon-to-be published paper focuses on surface temperature issues in general (Pielke et al. 2007). It strongly suggests that a new surface temperature index is needed for monitoring the climate system for global change. To date, the typical land surface temperature record is an *average* of the daytime high and the nighttime low. However, this research, our own research and that of others indicate that the nighttime low (more so than the daytime high) is affected by numerous local changes that are unrelated to the global climate concerns. These influences include increasing the surface roughness by adding orchards or buildings, changing natural cover to heat-soaking surfaces like asphalt, putting aerosols and dust in the lowest layer, heavy irrigation, etc.

The nighttime temperature over land occurs in a relatively shallow layer near the surface and thus is more strongly affected by changes in the properties at or near the surface as described above, be they land-use changes or atmospheric concentrations of aerosols. This implies that the more reasonable index to use for monitoring the global climate is the *daytime* maximum temperature which occurs at a time of day when a deeper layer of air is mixing down to the surface, mitigating the non-climate effects of those local changes. The daytime temperature then represents more closely what is happening in the deep atmosphere where changes due to such drivers as greenhouse gases occur. This idea will be mentioned later.

ATMOSPHERIC TEMPERATURE TRENDS

There was considerable media attention given to the Climate Change Science Program's 2006 report about temperature trends in the atmosphere, about 0 – 35,000 ft, versus those of the surface for the period since 1979. The basic task of the CCSP was to look at the various datasets of atmospheric and surface temperature and draw conclusions about their relative trends. Several atmospheric datasets revealed trends less than or the same as the surface, which is at odds with greenhouse theory as embodied in present-day climate models which anticipate a faster rate of warming in the upper air.

The key statement regarding GLOBAL trends in the report claimed, "This significant discrepancy no longer exists." It would have been more accurate in my view to have said, "The magnitude of these global discrepancies is not significant." This is a subtle but important difference because it not only acknowledges that discrepancies still exist but that the differences between the global surface and atmospheric trends are within the uncertainty bounds of our various measurements at this time. In other words, rather than being a statement claiming certainty of the measurements (and models) it should have been a statement claiming the uncertainty of our knowledge. I had proposed the second rendition, but was unsuccessful in seeing it implemented.

Be that as it may, the more interesting issue is found in the tropical region. Here we have significant discrepancies between surface and atmospheric trends for nearly all datasets. The tropical region is not trivial, constituting 1/3 of the global area.

The report acknowledged that reasons for this discrepancy were an "open question" but came to a "consensus" statement that the reason for the discrepancy was (a) errors common to models (b) errors in most observational datasets or (c) a combination of the two. The report says that the authors "favored" the second reason, i.e. observational error. The word "favored" was used to allow a sense of a majority view, since I did not agree with that assessment. I preferred the third option, that models and observations have roughly the same amount of error.

I was fairly happy with choosing option (c) because I knew of the two papers that were going to appear soon based on research sponsored by the Dept. of Energy, the Dept. of

Transportation and the National Oceanic and Atmospheric Administration (Christy and Norris 2006, Christy et al. 2007). In these papers I dealt specifically with atmospheric trends and the information we have to assess errors and uncertainties. In both papers we show that atmospheric trends from our UAH datasets are most consistent with independent measurements and thus imply that the discrepancy between the tropical surface and upper air trends is quite differently expressed in observations versus model output.

In the second of the papers, we examined eight upper air datasets in the tropics. All but one revealed less cooling aloft than at the surface. And, in all cases, these seven differed from the one "warming" dataset in the same way, something that would be highly improbable by chance if the one "warming" dataset was accurate. The conclusion of the paper was that there is very likely a difference between the surface and atmospheric tropical trends, with the atmosphere being cooler. This is significant because model simulations indicate the atmosphere should be warming faster than the surface by a factor of about 1.3 if greenhouse influences are correctly included in climate models. Thus, while all datasets indicate a warming trend in atmospheric temperatures, and therefore perhaps a consistency with some level of greenhouse forcing, the rate of the warming is (a) more modest than expected and (b) occurs in a different relationship to the surface than expressed by climate models.

PANEL QUESTIONS

Given the above information I would answer the questions posed to the panel as follows:

(1) Are global temperatures increasing?

> Averaged over the surface, over land and ocean, using both day and night temperatures together, the answer is yes. Over land, using *daytime* temperatures as a likely better indicator of overall climate change, the answer is yes, but at a small rate. In the lower atmosphere since 1979, the answer is yes, but at a rate nearly all datasets show is lower than projected from climate models relative to the surface.

(2) If global temperatures are increasing, to what extent is the increase attributable to greenhouse gas emissions from human activity as opposed to natural variability or other causes?

> No one knows. Estimates today are given by climate model simulations made against a backdrop of uncertain natural variability, assumptions about how greenhouse gases affect the climate, and model shortcomings in general. The evidence from our work (and others) is that the way the observed temperatures are changing in many important aspects is not consistent with model simulations. However, with extra greenhouse gases in the atmosphere there should be some impact on global surface and atmospheric temperatures, but the exact extent is unknown. Since 1950, the IPCC indicates from model simulations that "most" of

> the 0.5 °C surface warming (perhaps 0.3?) is due to the way models incorporate the effects of extra greenhouse gases.

(3) How do you expect future global temperatures to be affected by greenhouse gas emissions from human activity.

> If the simpler aspects of physics prevail in this complicated system, the surface temperature of the planet should rise. How much? The current rate is about 0.15 °C/decade, part of which is very likely due to extra greenhouse gas concentrations, and that rate seems fairly steady. Other questions related are: Will it be possible to detect in the global temperature the consequence of various legislated actions? (Almost certainly no.) What are the consequences of putting more of the basic building block of life, i.e. CO_2, into the air? (An invigorated biosphere.) How much is human life going to be improved by the fact energy will be used to enhance human existence? (A great deal, see below under Energy Policy)

MODEL EVALUATION

The inconsistencies between model output and observational data should raise concerns about model confidence. Frankly, I am surprised that so many in our climate community grant high confidence to model output while knowing the crudeness of the assumptions which characterize their construction relative to the complexity of the real world. But testing models is a considerable enterprise dominated now by those who are in some way associated with the modeling enterprise itself. It may be no surprise that many publications conclude that model output is valuable today for policymakers.

I am reminded, from my experience in the CCSP report, that model evaluation is often a restricted venture. It was a requirement in the CCSP that all observational datasets used in the report be publicly available in easy-to-access format. Some of us thought the same requirement should be applied to the global and tropical temperature averages from the climate model simulations, especially since those results had already been published the year before and the information was prominently displayed in the report.

In a curious email debate, those who did not want public access given to the climate model averages prevailed. I've encountered this asymmetry before in the field of climate science in which it has typically been very difficult to obtain climate model output in a useful format if at all. Progress has been made with the archiving of the "Climate of the 20th Century" model output at the Dept. of Energy's Lawrence Livermore Laboratory, but the effort required to retrieve specialized climate variables from scores of climate models is still Herculean. Most investigators do not have the infrastructure and personnel to spend time acquiring the huge raw datafiles for particular analyses and then climb a steep learning curve to process those files into the something useful.

This type of careful evaluation requires significant computational resources and personnel. However, such costs would represent a fraction of the millions allocated each year to modeling groups today. Having a series of significantly-funded, independent and rigorous evaluation projects to test models is absolutely essential for policymakers and represents good scientific principles. This is the path model evaluation must go for model output to be thoroughly assessed, documented and for progress to result.

More generally, there is a vital need for our nation to investigate "climate change" from all points of view. I submit that there should be a robust program to rigorously investigate outcomes of the climate change field that are not typically supported because they may not be seen as resulting in some alarming consequence or which have found a significant discrepancy that needs further study.

Using the best of all available datasets these studies would seek to characterize phenomena in the real world that may, for example, show a less sensitive climate system than currently represented in climate models. Such phenomena may lead to an understanding of a climate system that is more (or less) resistant to change than current models indicate. These studies would be done in the rigorous framework of hypothesis testing and peer-reviewed publication. As part of this effort, a thorough examination of climate indices, such as the daytime maximum versus the daily mean temperature, for their utility in understanding global changes vs. local changes would be enlightening. Because of the emotion surrounding the global warming issue, such proposals to investigate a potentially benign climate have a steep, uphill battle for funding opportunities as it struggles with the group-think that is encroaching into our profession. Yet a specific effort should be fostered to test and understand the many assumptions that underlie the current opinions of climate change that may lead to smaller changes than believed.

IPCC 2007

At this time, all we have are the "bullet points" of the IPCC *Summary for Policymakers*. As one of the contributing authors of the scientific text, I must wait until the full publication is released to understand more of the reasoning behind some of the points made in the IPCC. Contributing authors essentially are asked to contribute a little text at the beginning and to review the first two drafts. We have no control over editing decisions. Even less influence is granted the 2,000 or so reviewers. Thus, to say that 800 contributing authors or 2,000 reviewers reached consensus on anything describes a situation that is not reality.

I will comment on two of the bullet points, the first being one of the signature claims (paraphrasing for clarity) of the SPM: *we are 90% certain that most of the global surface warming since 1950 is due to humans* (actual statement is "Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations".) The reason for the not-so-certain "*very likely*" (i.e. 90%) confidence of the IPCC authors is that there are nagging problems related to the imperfections in the models' ability to reproduce many of the natural fluctuations found in the observed climate system. Had I had the opportunity to craft that statement, I would have wanted to include the idea of its origins. Perhaps something like this is more useful to policy makers, "Our current climate models are incapable of reproducing the surface temperature changes since 1950 without an extra push from the way these models incorporate the effects of extra greenhouse gases."

Another quote from the SPM that is over-interpreted is the phrase, "Warming of the climate system is unequivocal..." This statement seems designed to grant powerful confidence to a very simple idea that the observing systems we now have are able to tell us the earth's surface temperature is warmer now than it was 100 years ago and not colder (certainly a benefit). It says absolutely nothing about the cause of the warming. This becomes a problem of communication when the "unequivocal" bleeds into other claims as the media interprets the report.

All in all, the reductions in the scariest realizations is a welcomed change, i.e. reduction of the increases in sea level and average temperatures.

ENERGY POLICY

Discussions of climate for policy makers inevitably lead to questions about energy use. This leads me to discuss my perspective on energy use about which members have expressed gratitude in other hearings.

In 1900, the global energy technology supported 56 billion human-life-years (i.e. 35 yr life expectancy x 1.6 billion people – it's an index). Today, energy technology supports 426 billion human-life-years ... an eight-fold increase. Some of those human-life-years are mine. I've been allowed to become a grandparent, a situation which is now the rule, not the exception. An eight-fold increase in the global experience of human life is a spectacular achievement delivered by affordable energy.

It disturbs me when I hear that energy and its byproducts such as CO_2 are being demonized when in fact they represent the greatest achievement of our society. Where there is no energy, life is brutal and short. When you think about that extra CO_2 in the air, think also about an 8-fold increase in the experience of human life.

While preparing this testimony, I was reminded of my missionary experience in Africa. As you know, African women collect firewood each day and carry it home for heating and cooking. This source of energy, inefficient and toxic as it is, kills about 1.6 million women and children every year. When an African woman, carrying 50 pounds of firewood on her back, *risks her life* by jumping out in front of my van in an attempt to force me to give her a lift, I understand the value of energy. You see, what I had in my school van, in terms of the amount of gasoline I could hold in my cupped hands, could move her and her 50 pounds of firewood 2 or 3 miles down the road to her home. I now know what an astounding benefit and blessing energy is ... and to what extent she and her people would go to acquire it. Energy demand will grow because it makes life less brutal and less short.

The continuing struggle of the EU and other countries to achieve their self-imposed Kyoto targets, indeed falling behind the U.S. in the slowing of emissions growth, implies a lot of things, but two that stand out to me are (1) underestimating people's demand for energy and (2) the well-known tendency for countries and industries to "game the system" for their own benefits without contributing any real results to emissions reduction. An example of this second point is found in the recent announcement by some U.S. electric power producers who are promoting limits on CO2 emissions. These producers are heavily reliant on natural gas which is more costly than competing coal (and nuclear) power generators, but emits less CO2 than coal. By promoting an extra cost (i.e. tax) on coal-fired generation these groups hope to create a government-mandated competitive advantage (and an increase in public energy costs.)

This body is being encouraged to quote "do something" about global warming. The dilemma begins with the fact energy demand <u>will</u> grow because the benefits of affordable energy to human life are ubiquitous and innumerable. The dilemma turns to this question, "How can emissions be reduced in a way that doesn't raise energy costs, (especially for the many poor people of my state)?"

There are several new initiatives on emissions controls being proposed. It is difficult at this point to determine what impact each hopes to have on CO2 emissions. Much of the proposed reductions apparently deal with reducing non-CO2 greenhouse gases that may not be directly related to energy production. As a benchmark, for those which are in the ballpark of the Kyoto-like reductions, their relatively small effect on emissions implies a very small impact on whatever the climate does.

I've written a number of papers about the precision of our climate records. The impact of Kyoto-like proposals will be too small for we scientists to measure due to the natural variations of climate and the lack of precision in our observing system. In other words we will not be able to tell lawmakers with high confidence that specific regulations achieve anything in terms of climate in this country or the world. Additionally, the climate system is immensely complicated and really cannot be tweaked for a predictable outcome.

Humanity uses energy at a rate between 10 and 14 terawatts, 80% of which comes from sources which emit CO2. To have a 10% impact globally on CO2 emissions requires about 1,000 nuclear power plants now. Other options such as solar and wind are comparatively minuscule and troublesome as you will hear in future hearings (though they should be studied carefully) because of their current low intensity, intermittency, cost, transmission length (and losses), environmental impact and the problems of integrating a variable power supply into a baseload grid. So, to have even a minuscule impact on the climate system by 2050 or 2100, there would need to be a massive infrastructure change, the cost of which would be tremendous, both monetarily and socially (baring an innovation that is spectacular.) I recommend Robert Samuelson's *Washington Post* column from 7 Feb 2007 on this subject.

BIOFUELS

If the nation decides to make a strong commitment to invest in biofuels as a source of energy, there are some hurdles to overcome. The physics of ethanol, as a biofuel example, are not very attractive in terms of "energy in" vs. " energy out". There are also economic concerns regarding, specifically, ethanol expansion that deal with the specter of reduced production of other crops leading to price increases, and competition for corn within the corn market. However, the more agreeable means to accommodate a major expansion in corn production, is simply to grow more corn using land currently fallow. The brief discussion which follows addresses the point that *logistically*, it is possible to significantly increase corn (or other biofuel feedstock) production without distorting other markets.

It takes about 1000 gallons of water to grow enough corn to produce 1 gallon of ethanol on a 10ft by 10ft square. That's not sensible to do in a desert, but in Alabama, we receive on average 4,000 gallons of rain on that square every year. This suggests a sustainable production system is possible where water is plentiful. However, though the numbers demonstrate we have an abundance of rain to support biofuel feedstock, that rain often does not fall at the right time when crops are maturing in the hot summer.

To produce enough ethanol to make a dent in our liquid fuel requirements would require millions of acres of sustainable production in wet places. In Alabama, like other southeastern states, we've lost over 10 million acres of row-crop production because of lack of investment in irrigation - the kind of investment the federal government has been making for over 75 years in the West. A fraction of those billions, if spent on irrigation infrastructure in states like Alabama, would provide a way to dramatically increase acreage in production. If just one million acres of the 10 million Alabama has lost were reinvigorated with low-cost and environmentally sustainable irrigation systems, we would displace 10 million barrels of Middle Eastern oil per year. 2 million acres would produce 20 million barrels. Such volumes from Alabama alone (not to mention the other SE states) amounts to a significant contribution to U.S. energy needs. (Similar results would occur for other forms of biofuel feedstocks such as switchgrass if cellulose ethanol becomes feasible).

There are some benefits to this approach. (1) An area of our nation that is terribly economically depressed would be recharged – there are a lot of poor people in my state in these areas that would experience economic growth. (2) The U.S. balance of trade would be improved. (3) The stated congressional goal of energy security would be enhanced. And, (4) a measurable impact could be assessed on the regional and national economy as dollars are retained within the U.S. economy. Though ethanol is not without its concerns, one of those should not be a *logistical* barrier due to the perceived unavailability of land and water.

Though biofuels may provide a relatively small portion of the world's energy needs, the economic and security considerations may be the more forceful drivers which argue for increased production. The goal of reducing CO2 emissions by an appreciable amount will occur through innovation in other ways of energy production that lead to generation of high volume, baseload energy with reduced (or zero) emissions.

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Written Statement, March 7, 2007

Dr. Gabriele Hegerl, Duke University

I thank Chairman Boucher, Ranking Member Hastert and the Members of the Subcommittee for the opportunity to testify today, and I would like to also thank you for your leadership and interest in global warming. My name is Gabriele C. Hegerl. I recently had the pleasure of serving as a coordinating lead author on the U.N. Intergovernmental Panel of Climate Change's Fourth Assessment Report. Our report reflects a continued strengthening of the scientific evidence that human-caused global warming is occurring; we hope that it is helpful to policymakers seeking to address the issue.

First, a word on my background. I am a Research Professor at Duke University. I got my Ph.D. in applied mathematics at the Ludwig-Maximilians University in Munich, in a topic of numerical fluid dynamics. After that, I worked as Postdoctoral Scientist and then Research Scientist at the Max-Planck Institute for Meteorology in Hamburg, one of the world's leading climate modeling centers. I have since been a visiting scholar on a fellowship from the Alexander von Humboldt Association at the University of Washington, Seattle (1997-1999), a Research Scientist at Texas A&M (1999-2001) and have been a Research Professor at Duke since 2001. My scientific interest has been focused on understanding and determining the causes of observed climate change.

I have authored and coauthored about 50 scientific publications, and serve on a number of national and international committees, among them the National Research Council's Climate Research Committee, the National Center for Atmospheric Research (NCAR)'s advisory board for the Geophysical Statistics project, and the CLIVAR Joint Expert Team on Climate Change Detection and Indices. I have also served on the World Climate Research Program's (WCRP) Working Group on Coupled Modeling, 1999 to 2004.

I was a Lead Author of the Intergovernmental Panel on Climate Change (IPCC) Working Group I contribution to the Third Assessment Report, and am a Coordinating Lead Author of the Fourth Assessment Report that was just recently released. The chapter that I coordinated focuses on determining the causes of observed climate changes.

My testimony will answer three central questions: (1) Are global temperatures increasing? (2) are the increasing temperatures attributable to human activities? and (3) how do we expect future temperatures to be affected by continued human activity?

Key aspects of my answers are that there is unequivocal evidence that global temperatures are increasing. Secondly, a large body of scientific research shows that the observed changes in the global climate over the past half century strong reflect the "fingerprints" of greenhouse gas increases and other external influences on climate, leading the IPCC to conclude that most of the warming over the second half of the 20th century has very likely been due to greenhouse gas increases. If greenhouse gases keep increasing, we will see substantially more warming than observed over the 20th century. I attach a file with figures from my slide presentation to illustrate these key points. The figures are from the Summary for Policymakers or the Technical Summary for Working Group I of the IPCC Fourth Assessment Report.

1. Are global temperatures increasing?

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment report concluded that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level". This is a very strong statement, reflecting that the finding that warming is observed in many independent datasets, and that the observed changes are physically consistent with each other.

Direct measurements show that surface temperature warmed by 0.74°C over the past century (1906 to 2005, 5-95% range 0.56-0.92°C; this is a 1.3°F warming with a range of 1.0-1.7°F). This warming has been widespread, as seen in Figure 1. The largest amount of data is available during the second half of the century, when surface air temperatures, temperatures of the upper ocean, and temperatures of the lower atmosphere all increased and when most glaciers worldwide shrank. Therefore, evidence for warming is strong and comes from diverse parts of the climate system and many independent datasets.

2. If global temperatures are increasing, to what extent is the increase attributable to greenhouse gas emissions from human activity as opposed to natural variability or other causes?

Greenhouse gas increases caused very likely most of the warming over the second half of the 20th century.

The observed warming, illustrated in figure 1, far exceeds the magnitude of warming or cooling that is expected from variability generated internally within the climate system. El Nino is one example of this so-called "natural variability" of the climate system. The fact that all major components of the climate system have gained heat supports the assessment that an external influence on the climate system is responsible, since such a significant change can only be plausibly explained by a change in the energy balance of the planet. Therefore, IPCC concluded that it is "extremely unlikely" (less than 1 chance in 20) that this warming was due to the internal variability of the climate system.

We also know that influences outside the climate system, that is, external forcing, can cause variations in climate. For example, it is well documented that explosive volcanic eruptions, which eject sulfate aerosols into the upper atmosphere, cause a worldwide cooling during the few years following such events. This happens because the aerosols ejected by volcanoes into the upper atmosphere reflect some incoming solar radiation back to space. The cooling that occurs after such eruptions is visible in the modern instrumental temperature record (e.g., temperatures fell after the eruption of Mount Pinatubo in 1991, visible in figure 2). It is also visible in reconstructions of temperatures in the Northern Hemisphere over the last several centuries in conjunction with reconstructions of past volcanic activity from ice cores and historical records. In fact, multiple volcanic eruptions appear to have contributed substantially, for example, to the cool conditions of the Little Ice Age (~1450-1850).

Changes in solar radiation over time can also influence climate, but variations in solar radiation measured by satellite over the last 2-3 decades have been small in recent decades and can not explain the temperature increase over the same period. Based on statistical studies, we also concluded that the warming over the recent fifty years is very unlikely to have been due to natural causes alone.

By far the strongest influence on the energy budget of the planet (called "radiative forcing") since preindustrial times is the warming effect of the increase in greenhouse gases such as CO_2 and methane, and the partially offsetting cooling effect from sulfate aerosols. In the Fourth Assessment report, changes in the energy budget of the planet due to changes in solar radiation are estimated to be about a tenth of the total human-induced change in the energy balance of the planet, with non-overlapping uncertainty ranges. Changes in land cover and land use (e.g., replacement of forest with agricultural land) could have contributed to some regional temperature changes over the historical period. Changes in land surface characteristics are estimated to have caused a small cooling effect globally. Some recent model simulations have included the effect of land use change and find it very small on temperature averages over larger spatial scales.

When trying to explain observed temperature changes over the 20th century, it is important to consider all important external influences on climate, such as changes in solar radiation and volcanic eruptions as well as the increase in greenhouse gases, aerosols, and changes in ozone in the lower and upper atmosphere. Climate models integrate our understanding of the physics of climate, and simulate the changes in the climate system that are expected in response to external forcing. Climate models are evaluated extensively by their ability to simulate seasonal and short-term climate variations, and also to simulate conditions of past climate such as the Last Glacial Maximum or the mid-Holocene, a time when climate was quite different from today.

For the Fourth Assessment report, a very large number of such simulations from dozens of climate models worldwide has been available to study past and future climate. The second figure illustrates that climate models, when including all important external influences, reproduce the observed evolution of global mean temperature over the 20th century very well (top diagram). They reproduce the observed episodes of warming and the cooling following volcanic eruptions (indicated by vertical bars). The range that is covered by these simulations indicates the effect of variability internal to the climate system. Individual simulations are very similar in appearance to the observed record. In contrast, if anthropogenic greenhouse gas and aerosol influence is not included in the models, they cannot reproduce the warming, particularly in the second half of the 20th century, as is illustrated in the bottom panel.

However, we do not rely just on such an agreement to attribute observed climate change to causes. Instead, we use rigorous signal detection techniques to estimate the contribution of greenhouse gas increases to observed temperature changes, and rely on a careful examination of all plausible explanations of the observed warming including variability generated within the climate system. This is done by utilizing statistical methods to analyze the *observed* pattern of warming in space and time. Climate models are an important tool since they provide information about the "fingerprint" that different external influences are expected to have on climate. For example, volcanic eruptions are expected to cause short-term cooling. Changes in solar radiation cause warming throughout the lower and upper atmosphere, and follow the 11-year cycle of solar variability. Changes in greenhouse gases cause global warming, with greater warming over land than oceans, warming in the lower atmosphere, and cooling in the stratosphere. Sulfate aerosol and other anthropogenic influences cause cooling which is strongest over industrialized regions. Incorporating these effects into climate models enables one to develop a "fingerprint" of external influences on climate, and the statistical methodologies allow us to quantify the presence of such fingerprints in observations. Such studies allow for the possibility that the response to a forcing may be larger or smaller in observations than simulated in the models.

Based on many studies it was found that the best explanation of the observed warming over the recent 50 years involves substantial greenhouse warming, some of which was counteracted by cooling influences from other anthropogenic sources, and a small influence of natural forcing such as changes in solar radiation and volcanism. We also concluded that it is very likely that greenhouse gases caused more warming over the recent 50 years than solar forcing. This assessment does not consider the fact that solar forcing is estimated to be much smaller, but only relies on the observed pattern of changes.

Based on a large body of such work, the IPCC chapter I coordinated, together with Dr. Zwiers (Director of the Climate Research Division of Environment Canada), concluded that "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in greenhouse gas concentrations." The term "very likely" indicates an expert judgment, based on strong statistical evidence and physical understanding, and indicates that that there is more than a 9-in-10 chance that the statement is correct[1]. This assessment conservatively accounts for remaining uncertainties, such as observational uncertainty, uncertainty in some external forcings and uncertainty in the estimates of the expected responses to external forcing. We also find that it is likely that greenhouse gas forcing alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would have otherwise taken place.

Such work on attributing observed changes to causes has been carried over to warming over individual continents with similar conclusions (Figure 3). Only model simulations with greenhouse gas forcing reproduce the observed warming over each continent (there was insufficient data to make such an assessment over Antarctica). The figure also indicates that over each continent, average temperatures are far from where they would be without greenhouse gas influences. The successful simulation of the different warming rates over different continents and land and ocean provides strong evidence for a human influence on climate.

3. How do you expect future global temperatures to be affected by greenhouse gas emissions from human activity?

Global temperatures will continue to increase, both due to the warming that is already "in the pipeline" and with further increases in greenhouse gases.

Predictions of future warming are made using climate models that are forced with scenarios of future emissions. The predictions from the first two assessment reports, 1990 and 1996, can now be directly compared against actual observed temperature changes, and have proven to be quite realistic. Confidence in simulations is further enhanced by the very convincing simulation of 20th century temperature change in the ensemble of climate model simulations, as seen in figures 2 and 3 of my presentation.

Future warming will not be small, since we have now more confident estimates of the equilibrium climate sensitivity, which is the eventual warming that would be expected to occur in response to a doubling of CO_2 in the atmosphere. It has been long believed, based on climate models, that this sensitivity is between 1.5

[1] The IPCC uses calibrated language to describe the uncertainty on its assessments. For example, an assessment of "very likely" indicates a judgment, based on strong statistical evidence and physical understanding, that there are better than 9 chances in 10 that the assessed statement is correct.

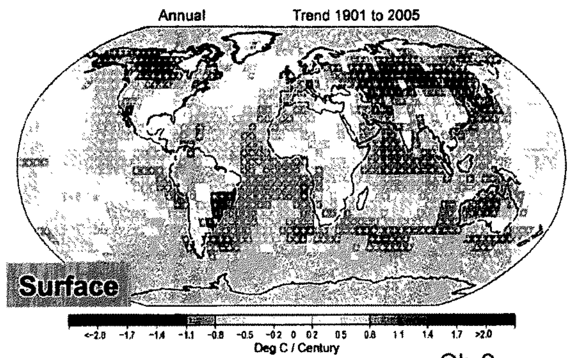
and 4.5°C (2.7 to 8.1°F). We now have data from observations that confirm this range. The observed estimate comes from the climate response to volcanic eruptions, the range of climate sensitivity in climate models that makes these models skillful at simulating climate change for present day conditions and the Last Glacial Maximum, and, most importantly, from a comparison between simulated and observed changes over the 20th century. The most confident IPCC AR4 conclusion from this work is that the "climate sensitivity is very unlikely below 1.5°C (2.7°F)". The most likely value was found to be about 3°C (5.4°F), and the likely range of climate sensitivity (i.e., the range that is expected to be correct with a probability of 66% or greater) is 2-4.5°C (3.6 to 8.1°F). This essentially rules out very small temperature changes in response to further increases in greenhouse gases.

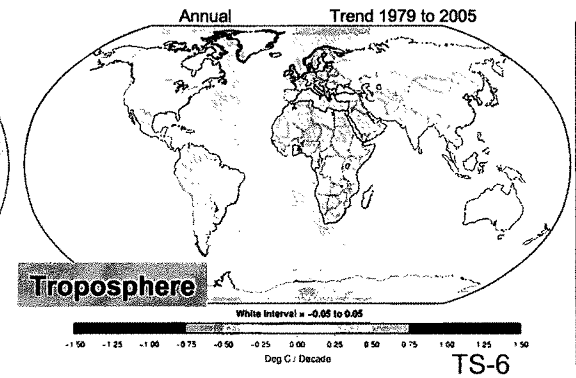
Future warming, particularly later in the 21rst century, depends on how CO_2 and other radiative forcings develop in the future. For the lowest emission scenario considered, warming ranges between 1.1 and 2.9°C (2.0 to 5.2°F) by the end of the 21rst century, which is about 1.5 to 4 times the observed warming from 1906-2005 of 0.74°C. For a high emission scenario, the future warming is expected to be about 3-9 times the warming observed in the past 100 years. Note that the emission scenarios considered by the IPCC report do not include mitigation policies.

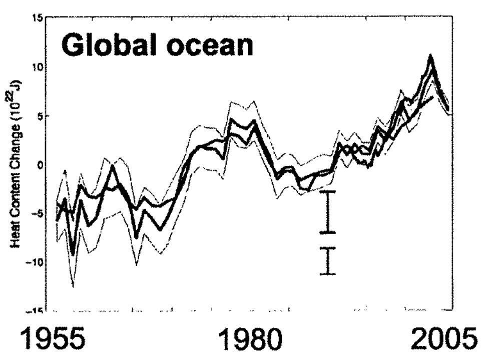
Thus, I would like to summarize that direct observations find that global temperatures have warmed, that anthropogenic greenhouse gas increases have caused a very large part of this warming, and that we expect continued warming. We are very confident that the sensitivity of the climate system to greenhouse gas increases is not small. The amount of future warming depends on the emission path chosen by societies, and extends to a further warming that is much larger than the one we have already observed.

On behalf of Duke University, I also want to communicate our willingness to work with you as you struggle with all of the hard issues associated with global warming. In the Nicholas Institute, we are building a one-of-a-kind conduit between the University and policymakers like you in collaboration with Duke faculty involved in all issues relating to climate change.

Observed widespread warming

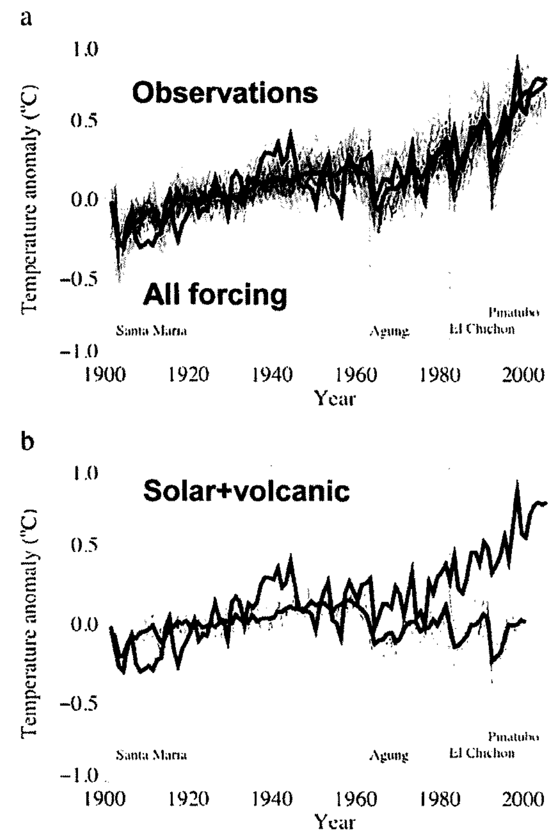






- unequivocal
- extremely unlikely without external forcing
- very unlikely due to known natural causes alone

- Anthropogenic greenhouse gas increases *very likely* caused most of the observed warming since mid-20th century

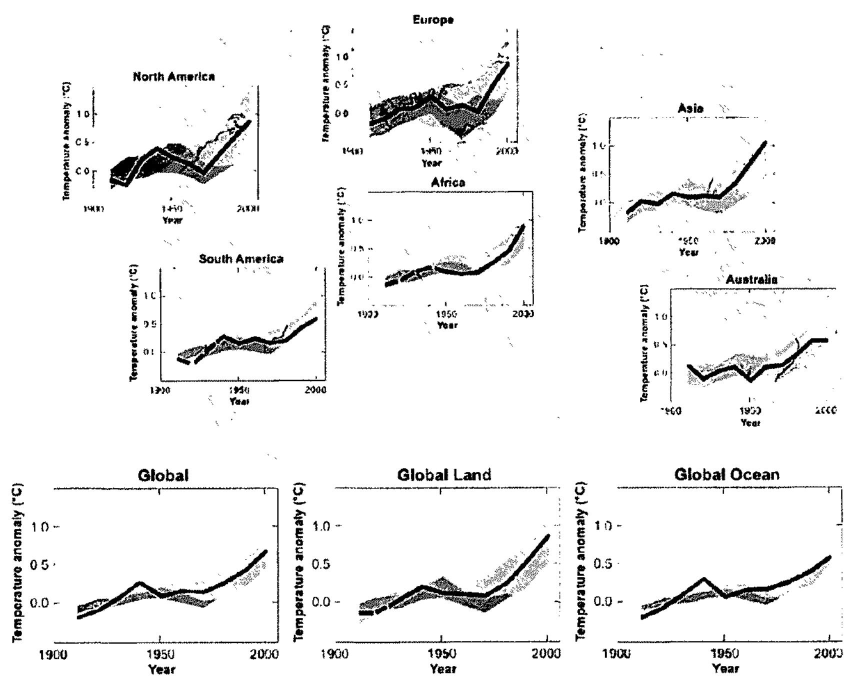


TS-23

Continental warming

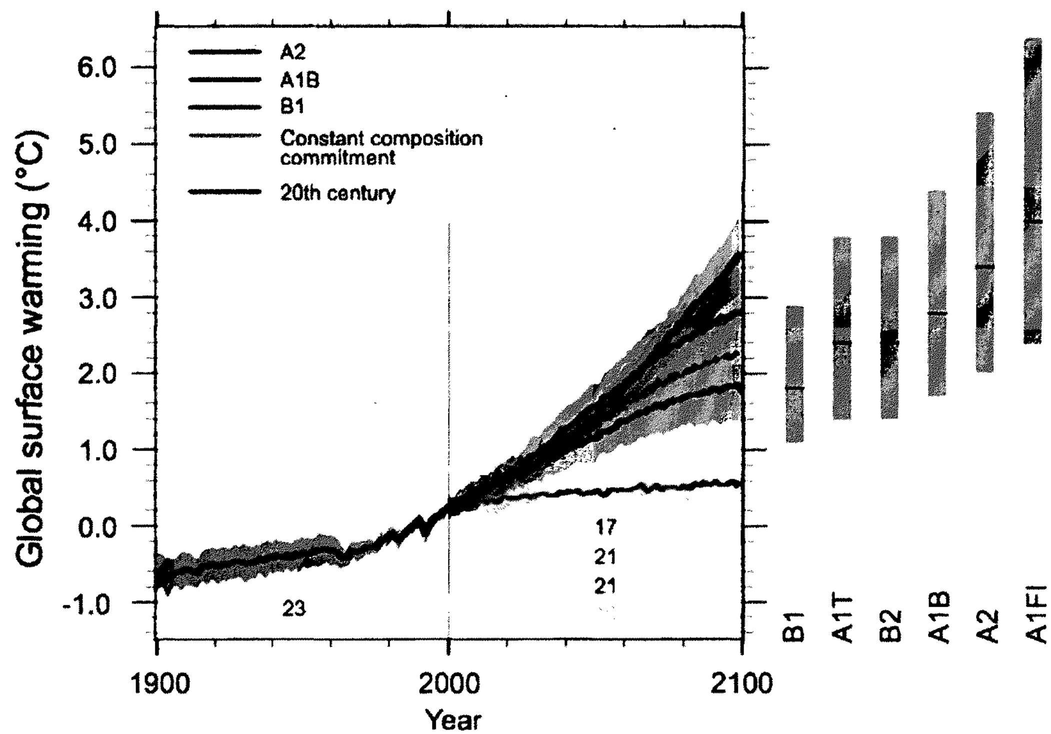
SPM-4

likely shows a significant anthropogenic contribution over the past 50 years



— Observations ■ All forcing ■ natural forcing

Future warming (IPCC)



Statement of Michael Oppenheimer
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Introduction

My name is Michael Oppenheimer. I am the Albert G. Milbank Professor of Geosciences and International Affairs at Princeton University, where my affiliations include the Department of Geosciences, the Woodrow Wilson School of Public and International Affairs, and the Princeton Environmental Institute. I have authored over 90 articles in peer-reviewed journals including papers on Earth's atmosphere and ice sheets, climate change and its impacts on the environment, and policies for responding to climate change, in addition to basic atomic and molecular physics and astrophysics. I recently served on the National Research Council's Panel on Climate Variability and Change. I am a lead author and contributing author to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), and was a lead author or contributing author to various chapters of the Second and Third Assessment Reports of IPCC. Before assuming my current position at Princeton University, I was chief scientist for Environmental Defense. I am currently a science advisor to this group. Earlier, I held the position of atomic and molecular astrophysicist at the Harvard-Smithsonian Center for Astrophysics.

I am grateful for the opportunity to testify before this committee on the subject of climate change. My testimony will address three questions posed by this committee, and my responses will be based on the Working Group I section of the Fourth Assessment Report of the IPCC, *Climate Change 2007: The Physical Science Basis*, as well as my own research and review of the literature. In addition, I will address the subject of ice sheets and sea level rise which received considerable attention in the wake of the publication of the Summary for Policy Makers of the IPCC report. Finally, I will report some recent findings from the literature on the question of the time remaining to avoid levels of climate change that some research has characterized as "dangerous".

I want to emphasize that I am testifying in my capacity as an individual scientist, and not as an official representative of the IPCC or Princeton University. While I largely base my testimony on, and specifically cite, the recent IPCC report and other relevant literature, the conclusions drawn here are my own.

Question 1: Are global temperatures increasing?

The Fourth Assessment uses unusually definitive language in stating, "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level". It is noteworthy that evidence for a pervasive global warming since the mid-19th century comes not only from surface temperature measurements but also from temperatures inferred from measurements aloft, temperatures at and beneath the ocean surface, and temperature trends on six of the seven continents (excluding Antarctica). Furthermore, IPCC points to the broad response of the Earth system as a whole as evidence of the warming, most particularly the decline of snow and ice cover including the shrinkage of glaciers, and global sea level rise of 5 to 9 inches over the 20th century.

(To put the rate of sea level rise in perspective, I would like to point to estimates that along typical sandy stretches of the US east coast, a one-foot sea level rise leads to about 100 feet of land loss by erosion and submergence [1]).

Most striking is the finding that rates of warming and sea level rise have both accelerated. The warming trend over the last 50 years, about a quarter of a degree Fahrenheit per decade, is nearly twice that for the last 100 years. Furthermore, the report notes, "There is *high confidence* that the rate of observed sea level rise increased from the 19th to the 20th century". The rate of rise from 1993 to 2003 is about 70% greater than that from 1961 to 2003, although there is uncertainty over whether the rapid rate of rise will persist, decrease, or increase.

Another striking finding is that, unexpectedly, the major ice sheets in Greenland and Antarctica (particularly the West Antarctic ice sheet) are both shrinking. The report notes that losses from the ice sheets of Greenland and Antarctica have very likely contributed to sea level rise over 1993 to 2003 (about 15% of the total sea level rise observed over that period, but with a large uncertainty). More recent research than that included in the IPCC report suggests the rate of ice sheet loss has continued to accelerate [2].

It is particularly noteworthy that the report firmly dispensed with some earlier assertions which have sometimes been misused in the public debate on global warming. Among these were the attribution of the global warming trend to the heat island effect; an apparent discrepancy between temperatures inferred from balloon-borne and satellite measurements of the lower- and mid-troposphere and the surface temperature record; doubts that water vapor, a key amplifier of warming, is indeed building up in the atmosphere; and the notion that the rate of sea level rise has been constant for many centuries.

<u>To summarize in my own words:</u> *Global temperatures are certainly increasing, the warming and associated sea level rise have accelerated, and a pervasive global climate change is well underway.*

Question 2: If global temperatures are increasing, to what extent is the increase attributable to greenhouse gas emissions from human activity, as opposed to natural variability or other causes?

IPCC also reached a very strong conclusion on this point: "Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations". The IPCC report emphasizes that the human influence now has been discerned in specific aspects of climate, including ocean temperatures, continental-average temperatures, temperature extremes and wind patterns. A significant human influence over temperatures has *likely* been discerned for all continents but Antarctica. "Temperatures of the most extreme hot nights, cold nights and cold days are *likely* to have increased due to anthropogenic forcing. It is *more likely than not* that anthropogenic forcing has increased the risk of heat waves".

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These findings come from two sources. Most important are statistical comparisons of the geographic pattern of temperature and other climate changes, and their evolution over time, with patterns produced by computer models. Such models estimate changes in the climate system that should have occurred as greenhouse gas levels increased over time. These are compared with modeled estimates of the effect of natural climate variability, and the effects of changes in the sun and volcanic emissions, that is, temperature changes that might have occurred absent the greenhouse-gas increase. Such comparison allows the effect of natural variability, the sun, and volcanoes to be separated from the effect of the greenhouse gases.

Another source of information is analysis of so-called paleo-climate proxies, indirect indicators of climate that are used to infer temperature changes for periods before a reliable thermometer record is available. These include data retrieved from ice and sediment cores, tree rings, and pollen. Temperatures inferred using such methods have greater uncertainty than direct measurements. Nevertheless, IPCC reached certain key conclusions with increased confidence since its last assessment. Among these, I cite two verbatim:

- Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years.

- The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres (about 13 to 20 feet) of sea level rise.

I shall return to discuss the broad implications of the second point later in this testimony.

IPCC's judgments on likelihood take into account uncertainties inherent in both methods. For example, it is not possible at this time to ascribe small-scale climate changes, i.e., those taking place over distances smaller than a continent, to the greenhouse gas buildup.

Once again, the IPCC sought to put to rest two issues that have clouded the public discussion of climate change. It has often been asked why warming occurred in the early 20th century before the bulk of human emissions of the greenhouse gases occurred. IPCC states that "it is likely that anthropogenic forcing (i.e., the human-made climate-changing effect of greenhouse gases) contributed to the early 20th century warming evident in these records". Changes in volcanic emissions and solar radiation also made significant contributions to the earlier warming. Second, IPCC notes that between 1750 and today, changes in the sun contributed less than 10% of the climate forcing due to human activities.

<u>To summarize in my own words:</u> *It is very likely that most of the recent climate change is attributable to human activities, particularly emissions of greenhouse gases and aerosol particles. Natural climate variability and changes in the sun and volcanic emissions have played a lesser role.*

Question 3: How do you expect future global temperatures to be affected by greenhouse gas emissions from human activity?

Obviously, answers to questions about the future are attended by much greater uncertainty than those about the past. Projections of future global temperatures depend on the sensitivity of the climate and the amount of greenhouse gases emitted. The Fourth Assessment provides improved guidance on the question of climate sensitivity, which is defined as the response of global average temperature to a doubling of carbon dioxide levels in the atmosphere:

- Climate sensitivity is *likely* to be in the range 3.6 to 8.1 degrees Fahrenheit with a best estimate of about 5.4 degrees, and is *very unlikely* to be less than 2.7 degrees.

- Values substantially higher than 8.1 degrees Fahrenheit cannot be excluded.

Future emissions depend on the size of Earth's population, the state of economic development, and technologies employed and lifestyles pursued. What sort of motor vehicles, if any, will be dominant a century from now? How many will be owned by a typical family in the US? In China? What sorts of engines and fuels will power them? How efficient in their use of fuels will they be? How far will they be driven in a typical year? This is only one set of questions that must be answered to project futures emissions. Obviously, there is a range of plausible responses, and these are captured by IPCC in emissions scenarios reported in its Special Report on Emissions Scenarios.

These scenarios indicate that the carbon dioxide concentration in the atmosphere will approach or exceed a doubling in this century absent policies to limit emissions. Furthermore, Earth's warming is delayed by the slow heating of the oceans. Accounting for these factors, models project a warming of 2 to 11.5 degrees Fahrenheit during the 21st century. If emissions are low (which is more likely to occur with explicit global policies to reduce emissions) a warming of 2-5.2 degrees Fahrenheit is expected. If very fast and sustained emissions growth occurs with no restrictions, warming of 4.3-11.5 degrees Fahrenheit is expected. Many intermediate scenarios are plausible, producing intermediate ranges.

Let me emphasize two points:

- A larger warming than these global mean values is expected over land and at high northern latitudes, such as the upper plains and upper Midwest regions of the US.

- Some additional warming above today's temperatures is inevitable both due to gases already emitted and because an overnight turn-around in emissions is not possible.

Combined with the findings of others studies, the IPCC projections indicate that the warming would likely be larger and occur faster than any global temperature change in the history of civilization, and this is potentially the case even if emissions are reduced promptly. If instead emissions occur at the high end of projections and climate sensitivity is high, the scale and scope of change would be unprecedented in millions and perhaps tens of millions of year, and, in my personal view, would be disastrous.

Global climate change accompanying projected warming will be sweeping. Among the changes projected by IPCC are:

- It is *very likely* that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent.

- It is likely that future tropical cyclones (typhoons and hurricanes) will become more intense.

- Sea level would continue to rise for centuries.

To summarize in my own words: During this century, global mean temperatures are expected to increase by amounts that are larger and occur faster than any in the history of civilization and reach levels perhaps not seen in tens of millions of years when ice sheets were much reduced and sea level was much higher than today. The temperature change would be largest on land and at high latitudes, broadly affecting key aspects of the climate system and remaking the face of the Earth.

Sea Level Change and the Ice Sheets

The greatest impact of warming to the US and many other areas may come from rising seas, but estimating future sea level rise has proven difficult for both the 21st century and for the longer term. The key uncertainty lies in how the ice sheets in Greenland and Antarctica will behave as Earth warms. The Greenland ice sheet contains an equivalent of about 23 feet of sea level rise and the West Antarctic section of the Antarctic ice sheet, the part of the larger ice sheet thought most vulnerable to warming, alone contains an equivalent of about 17 feet of sea level rise.

Rapid collapse of small, floating ice shelves in West Antarctica has been followed by unexpected acceleration into the sea of the land-based ice in back of the ice shelves, adding to sea level rise. The Greenland ice sheet has also experienced unexpected dynamical changes as "outlet" glaciers terminating in the sea, as well as other parts of the ice sheet have accelerated, doubling the contribution to sea level rise since the early 1990s due to melting alone.

The unfortunate truth of the matter is that, in contrast to success of projections of atmospheric warming, no computer models exist that can reproduce the recent changes in the ice sheets, called "dynamical" because they involve ice flowing into the sea rather than merely ice melting away. Consequently no reliable basis exists for projecting the future of the ice sheets. The failure of models is particularly stark for Antarctica because there the models had projected a significant *growth* in the ice sheet due to increased precipitation from the warming global atmosphere. Instead, the Antarctic ice sheet as a whole probably has lost rather than gained ice recently largely due to rapid losses in the Amundsen Sea region of West Antarctica.

Faced with this uncertainty, IPCC projects 7 to 15 inches of sea level rise for this century if emissions are low, and 10 to 24 inches if emissions are high, *excluding future rapid dynamical changes in ice flow* (emphasis mine). In other words, these estimates assume that the rates of loss of ice from Greenland and Antarctica will not continue to accelerate. Surely this is an optimistic assumption [3], and IPCC recognized as much in providing some additional scenarios (from among many plausible ones) of additional dynamical change that produce higher sea level rise.

These problems make the projection of long term changes beyond the 21^{st} century even more complex. But IPCC did provide important information relevant to this question:

- Global average sea level in the last interglacial period (about 125,000 years ago) was *likely* 13 to 20 feet higher than during the 20th century, mainly due to the retreat of polar ice. Ice core data indicate that average polar temperatures at that time were 5 to 9 degrees Fahrenheit higher than present...

I would like to point out that a future global warming of only 3- 4 degrees Fahrenheit may be sufficient to cause 5 degrees of polar warming. Disintegration of much of the Greenland and part of the West Antarctic ice sheet may follow. Paleo-climate studies reported in the literature provide little guidance on the possible rate of sea level rise for such warming. One study does suggest that rates could have approached 3 feet per century as sea level rose to 13-20 feet above the current level [4], a point not noted in the IPCC Summary for Policy Makers. Such rates could reasonably be characterized as catastrophic for many regions if they occurred again in the future.

To address this point further, I paraphrase IPCC:

- Current models suggest that a global warming of 2.2 to 7 degrees Fahrenheit from present, if sustained for millennia, would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m.

It is interesting that the conclusions from the models and the conclusions from paleo-climate data are similar in foreseeing large scale polar ice loss with temperature changes that are less than or comparable to what may occur over this century. The nub of the problem is whether we can trust the models in their claim that it would take millennia for the Greenland ice sheet to disintegrate once the process begins. Based on the fact that these very same models are not capable of reproducing recent dynamical ice loss, and that dynamical processes are an important control on the rate of disintegration, I conclude that we cannot trust the model estimate of a millennial timescale. It is entirely plausible that loss of large parts of the polar ice sheets, and a very large sea level rise over the course of several hundred years, rather than over millennia, would occur once the world warms as little as 3-4 degrees Fahrenheit above the present global mean temperature.

The models also assign little role to the West Antarctic ice sheet in the sea level rise for such modest warming. But the paleo-climate data indicate Antarctica likely played a role along with Greenland in causing the 13 to 20 foot rise of the distant past [4]. Accordingly, based on both recent observations and the distant past, the models have little credibility in their projections of the rate of ice loss from Antarctica, particularly the West Antarctic ice sheet.

Implications for Policy

Given that a warming of 3-4 degrees Fahrenheit above the present global mean may represent a plausible limit for avoiding "dangerous" climate changes [5], what does such a limit imply for actions to reduce emissions? This issue goes beyond the remit of IPCC Working Group I, so I will draw on the peer reviewed literature directly. The answer is that the chances of avoiding such a warming appear to be less than 50-50 if atmospheric concentrations of carbon dioxide are permitted to exceed 450ppm [6].

Unless the growth in global emissions is reduced soon, first through reductions in emissions in developed countries like the United States, later by measures in developing countries, global temperature is likely eventually to climb above the 3-4 degree Fahrenheit limit. Then the ice sheets may gradually shrink, causing sea level to rise 13 to 20 feet, possibly over as brief a period as several centuries. And if the warming were allowed to continue, that would be only the beginning of a process that would eventually lead to total loss of both the Greenland and West Antarctic ice sheets, and a much larger sea level rise.

Only prompt and sizable reductions in global emissions, hopefully carried out with the leadership of the United States, and in collaboration with other large emitters such as the EU, Japan, China, and India, would avoid such an eventuality. I point to the five-, ten-, and fifteen-year mandatory emission reduction targets embodied in the proposal from USCAP [7] as plausible initial steps to meeting this challenge.

There are many areas of scientific research where additional federal support is sorely needed, even while emissions reductions are being implemented. Clearly, one of the highest priorities ought to be developing a new generation of computer models of Earth's ice sheets.

It is apparent to me, and I hope to everyone else, that the US and all other countries ought to prepare to deal with a warmer world in any event. It is even more important to note that the window of opportunity to avoid potentially disastrous outcomes may be closing fast.

Thank you.

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Statement of

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Before the

U.S. House of Representatives Subcommittee on Energy and Air Quality

Committee on Energy and Commerce

7 March 2007

Hearing on

Climate Change: Are Greenhouse Gas Emissions from Human Activities Contributing to a Warming of the Planet?

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* Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect those of the National Science Foundation.

** The National Center for Atmospheric Research (NCAR) is sponsored by the National Science Foundation.

SUMMARY OF MAJOR POINTS—TESTIMONY OF JAMES W. HURRELL—MARCH 7, 2007

ARE GLOBAL TEMPERATURES INCREASING?

The iconic statement from the observations chapter of the IPCC Fourth Assessment Report (AR4) is the "warming of the climate system is unequivocal." This is based on an increasing number of many independent observations that give a consistent picture of a warming world. A limited sample of the evidence includes:

- Average global surface temperature has warmed over the last 50 years, with a greater rate of 0.17δC (0.3δF) per decade since 1979.
- Global average sea surface temperatures have warmed 0.35δC (0.6δF) since 1979.
- Global sea level has risen at a rate of 0.31 cm per year since 1993.
- Arctic summer sea-ice extents and Northern Hemisphere snow cover have decreased, and permafrost layer temperatures have increased since the 1980's.
- The number of heat waves globally has increased, and there have been widespread increases in the numbers of warm nights. Frost days are rarer.

To what extent is the increase attributable to greenhouse gas emissions from human activity as opposed to natural variability or other causes?

Climate model simulations have now reliably shown that global surface warming of recent decades is a response to the increased concentrations of greenhouse gases and sulfate aerosols in the atmosphere. When the models are run with natural forcing changes alone, they fail to capture the large increase in global surface temperatures over the past 25 years. Moreover, the spatial pattern of observed warming, which includes greater warming over land than over the ocean, is only simulated by models that include anthropogenic forcing. Discernible human influences now extend to other aspects of the climate as well, including ocean warming, continental-average temperatures, temperature extremes, and changes in precipitation.

How will future global temperatures be affected by greenhouse gas emissions from human activity?

The ability of climate models to simulate the past climate record gives us increased confidence in simulations of the future. Some major conclusions from the IPCC AR4 are:

- The rate of the projected global warming is near 0.2 Celsius per decade through 2030 regardless of the emission scenario. Likewise, warming and significant changes in precipitation will continue over each inhabited continent.
- By the middle of the 21st century the choice of scenario becomes more important.
- Continued greenhouse gas emissions at or above current rates would very likely induce many changes in climate much larger than those observed to date.
- Snow cover and sea ice coverage are projected to contract.
- It is very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent.
- Even if greenhouse gas concentrations were to be stabilized, anthropogenic warming and sea level will continue for centuries.

Introduction

I thank Chairman Boucher, Ranking Member Hastert, and the other Members of the Subcommittee for the opportunity to speak with you today on observed and likely future changes in climate and the contribution from human activity to those changes. My name is James W. Hurrell. I am a Senior Scientist at the National Center for Atmospheric Research in Boulder, Colorado, where I am also the Director of the Climate and Global Dynamics Division. My personal research has centered on empirical and modeling studies and diagnostic analyses to better understand climate, climate variability and climate change. I have authored or co-authored nearly 70 peer-reviewed scientific journal articles and book chapters, as well as dozens of other planning documents and workshop papers. I have given more than 75 invited talks worldwide, as well as many contributed presentations at national and international conferences on climate. I have also convened over one dozen national and international workshops, and I have served on several national and international science-planning efforts. Currently, I am extensively involved in the World Climate Research Programme (WCRP) on Climate Variability and Predictability (CLIVAR). I am the former co-chair of Scientific Steering Committee of U.S. CLIVAR, and I am the current co-chair of the Scientific Steering Group of International CLIVAR. I have also been involved in the assessment activities of the Intergovernmental Panel on Climate Change (IPCC) as a contributing author to chapters in both the Third and Fourth Assessment Reports, and I have served on several National Research Council (NRC) panels. I was a lead author on the U.S. Climate Change Science Program's (CCSP) Synthesis and Assessment Product on Temperature Trends in the

Lower Atmosphere, and I am currently serving on a NRC committee tasked to provide strategic advice to the CCSP.

Throughout this testimony I will refer extensively to the IPCC. Briefly, the IPCC is convened by the United Nations jointly under the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). Its mandate is to provide policymakers with an objective assessment of the scientific and technical information available about climate change, its environmental and socio-economic impacts, and possible response options. The IPCC reports on the science of global climate change and the effects of human activities on climate. It does not do or manage research. It has provided policymakers assessment reports since 1990, and the Fourth Assessment Report (AR4) is being released this year. Each IPCC report reviews all the published literature over the previous 5 years or so, and assesses the state of knowledge, while trying to reconcile disparate claims, resolve discrepancies and document uncertainties. The IPCC assessments are produced through a very open and inclusive process. The volunteer authorship of the AR4 in Working Group I (WGI) includes 152 lead authors and over 400 contributing authors from over 130 countries. In addition, there were more than 30,000 comments from over 600 reviewers, as well as formal coordinated reviews by dozens of world governments, including the U.S. All review comments must be addressed, and review editors are in place for each chapter of the report to ensure that this is done in a satisfactory and appropriate manner.

In today's testimony I have been asked to address three specific questions, all related to surface temperature. My answers to each will draw upon the same literature assessed by IPCC WGI, and they will reference several of the major conclusions highlighted in the

WGI Summary for Policymakers (SPM) released 2 February, 2007 in Paris, France. The WGI is tasked with appraising how and why the climate has changed, including the role of human activity, and it assesses projections of future climate change based upon various emission scenarios. The other two IPCC Working Groups deal with impacts of climate change, vulnerability, and options for adaptation and mitigation, including possible policy options.

Are global temperatures increasing?

Analyses of instrumental measurements of surface temperature averaged across the globe reveal a warming rate of about 0.17°C (0.3°F) per decade since 1979, and 11 of the last 12 years rank among the 12 warmest years since 1850 (1996 being the exception). Since the release of the IPCC Third Assessment Report (TAR) in 2001, the four years of 2002-2005 were the warmest in the historical record behind only 1998 (when a strong El Niño event enhanced the warming). The 2006 average global surface temperature is near the average of the past five years, and it was the warmest on record over the United States. Global land regions have warmed the most (0.7°C or 1.3°F) since 1979, with the greatest warming in the boreal winter and spring months over the Northern Hemisphere (NH) continents. The updated 100-year linear trend (1906–2005) of 0.74°C (1.4°F) is therefore larger than the corresponding trend for 1901-2000 given in the TAR of 0.6°C. Over the last 50 years, the rate of warming is nearly double that of the 100-year trend.

There is a very high degree of confidence in the global surface temperature values and the change estimates. Independent teams of scientists have laboriously analyzed and improved the historical surface temperature data, and trend estimates from the different groups are very similar over all time periods. The maximum difference, for instance, among three independent estimates of global surface temperature change since 1979 is 0.01°C per decade. Spatial coverage has improved, and daily temperature data for an increasing number of land stations have also become available, allowing more detailed assessments of extremes, as well as potential urban influences on both large-scale temperature averages and microclimate. It is well documented, for instance, that urban heat island effects are real, but very local, and they have been accounted for in the analyses: the urban heat island influence on continental, hemispheric and global average trends is at least an order of magnitude smaller than decadal and longer timescale trends.

There is no urban heat bias in the sea surface temperature (SST) record. Over the global oceans, surface temperatures have warmed 0.35°C (0.6°F) since 1979, and the warming is strongly evident at all latitudes over each of the ocean basins. Moreover, the warming is evident at depth as well. Since 1961, for instance, the average temperature of global ocean water has increased from the surface to depths of at least 3000 m, indicating that the ocean is absorbing most of the heat being added to the climate system.

The ocean warming causes seawater to expand and, thus, contributes to sea level rise. Instrumental measurements of sea level indicate that the global average has increased 0.18 cm per year since 1961, with a faster rate of 0.31 cm per year since 1993. Over the last century, global sea level rose approximately 17 cm. While much (60%) of this rise is due to thermal expansion, there are other sources of increased ocean volume, including melting from glaciers and ice caps. New satellite data records over the past decade also indicate that mass losses from the ice sheets of Greenland and Antarctica have also likely contributed to global sea level rise, but only recently. In addition, flow speed has recently increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior. Notably, the observation of consistent sea level rise is powerful evidence that the globe has warmed: there is no other explanation.

The aforementioned changes in global average surface temperature, SST and sea level do not imply, however, that changes are uniform around the globe. There are notable regional and seasonal variations, especially over relatively short time periods (year-to-year and even decade-to-decade). Regional differences in SST change arise, for instance, from natural variability and other factors. One example is the very strong warming of the central and eastern tropical Pacific Ocean that occurs during El Niño events. These events also produce regional ocean cooling over portions of the subtropics and the tropical western Pacific. Over the Atlantic, the average basin-wide warming is imposed on top of strong, natural variability on multi-decadal time scales. The level of natural variability, in contrast, is relatively small over the tropical Indian Ocean, where the surface warming has been steady and large over recent decades. These important differences in regional rates of surface ocean warming also affect the atmospheric circulation, producing changes in the atmospheric flow so that some regions warm more than others, while other regions cool, especially over periods of years or even decades. Yet, numerous changes in regional climate have been observed that are consistent with longer-term surface warming.

Snow cover has decreased in many NH regions, particularly in the spring season, and this is consistent with greater increases in spring than autumn surface temperatures in middle latitude regions. Sea-ice extents have decreased in the Arctic, particularly in the spring and summer seasons (7.4% per decade decrease since 1978), and this is consistent with the fact that the average annual Arctic temperature has increased at almost twice the global average rate. Arctic sea-ice extents were at record low values in 2005, which was also the warmest year since records began in 1850 for the Arctic north of 65°N. There have also been decreases in sea-ice thickness. Temperatures at the top of the permafrost layer in the Arctic have increased since the 1980s (up to 3°C locally), and the maximum area covered by seasonally frozen ground has decreased by about 7% in the NH since 1900, with an even greater decrease in the boreal spring. There has been a reduction of about two weeks in the annual duration of northern lake and river ice cover.

In contrast to the Arctic, there is no significant trend in Antarctic sea ice since the end of the 1970s, which is consistent with the lack of a trend in surface temperature south of 65°S over that period. However, the warming of the Peninsula region since the early 1950s is one the largest and the most consistent warming signals observed anywhere in the world. Large reductions in sea-ice have occurred to the west in the Bellingshausen Sea, and on the eastern side of Peninsula, and large reductions in the size of Larsen Ice shelf have occurred.

For any change in mean temperature, there is likely to be an amplified change in extremes. Extreme events, such as heat waves, are exceedingly important to both natural systems and human systems and infrastructure. We are adapted to a range of natural weather variations, but it is the extremes of weather and climate that exceed tolerances. Widespread changes in temperature extremes have been observed over the last 50 years. In particular, the number of heat waves globally has increased, and there have been widespread increases in the numbers of warm nights. Cold days, cold nights and days with frost have become rarer.

Long-term changes in upper-air temperatures are less certain than those at the surface. This is because of sparser spatial coverage and fewer observations overall, significant and frequent changes in instrumentation, and difficulties adjusting and merging different satellite records, among other factors that make the creation of long-term, homogenous upper-air temperature records difficult. Nevertheless, available measurements indicate global average warming in both the lower and the middle troposphere that is broadly consistent with the observed surface temperature change, largely reconciling a discrepancy that was noted in the TAR. A warmer atmosphere can also hold more water vapor, and indeed the average atmospheric water vapor content has increased since at least the 1980s over both land and ocean. For example, total column water vapor has increased over the global oceans by 1.2% per decade since 1988, consistent in pattern and amount with observed changes in SST and a fairly constant relative humidity. Increases in water vapor also mean that there is a greater supply of atmospheric moisture to storms; in fact, increases in moderate to heavy precipitation events have been observed over most land areas in recent decades.

Finally, paleoclimate data put the instrumental record into a much longer-term perspective. Based on reconstructions of temperature from proxy data, like tree rings, boreholes and ice cores, average NH temperatures over the last 50 years were very likely[1] higher than any other 50-year period in the last 500 years, and they were likely the highest in the past 1,300 years. These conclusions, articulated in the IPCC AR4, are also consistent with the principal findings of an independent study by the NRC in 2006. The task of the NRC committee, which was formed in response to a Congressional request,

[1] The IPCC AR4 defines the term "very likely" as the likelihood of a result exceeding 90%, and the term "likely" as exceeding 66%.

was to assess the state of scientific efforts to reconstruct surface temperature records for the Earth over approximately the last 2,000 years.

In summary, there are an increasing number of many independent observations that give a consistent picture of a warming world. Such multiple lines of evidence, the physically consistency among them, and the consistency of findings among multiple, independent analyses, form the basis for the iconic phrase of the observations chapter in the AR4 assessment: namely, that the "warming of the climate system is unequivocal".

If global temperatures are increasing, to what extent is the increase attributable to greenhouse gas emissions from human activity as opposed to natural variability or other causes?

To assess the causes of climate change, the IPCC first considers all the possible agents of climate change (forcings), both natural and from human activities. It also assesses the capabilities of climate models to simulate the past climate, given both the observations and estimates of past forcings, and the climate changes. Given good replications of the past, the forcings can be inserted one by one to disassemble their effects and allow attribution of the observed climate change to the different forcings.

Therefore, climate models are a key tool to evaluate the role of various forcings in producing the observed changes in global temperature. The best climate models encapsulate the current understanding of the physical processes involved in the climate system, the interactions, and the performance of the system as a whole. They have been extensively tested and evaluated using observations. They are exceedingly useful instruments for carrying out numerical climate experiments, but they are not perfect, and some models are better than others. Uncertainties arise from shortcomings in our understanding of climate processes operating in the atmosphere, ocean, land and cryosphere, and how to best represent those processes in models. Yet, in spite of these uncertainties, today's best climate models are now able to reproduce the climate of the past century, and simulations of the evolution of global surface temperature over the past millennium are consistent with paleoclimate reconstructions.

As a result, climate modelers are able to test the role of various forcings in producing observed changes in climate, for instance over the past century. Forcings imposed on the climate system can be natural in origin, such as changes in solar luminosity or volcanic eruptions, the latter adding considerable amounts of aerosol to the upper atmosphere for up to two years. Human activities also increase aerosol concentrations in the atmosphere, mainly through the injection of sulfur dioxide from power stations and through biomass burning. A direct effect of sulfate aerosols (small milky white particles readily seen from airplane windows) is the reflection of a fraction of solar radiation back to space, which tends to cool the Earth's surface. Other aerosols (like soot) directly absorb solar radiation leading to local heating of the atmosphere, and some absorb and emit infrared radiation. A further influence of aerosols is that many act as nuclei on which cloud droplets condense, affecting the number and size of droplets in a cloud and hence altering the reflection and the absorption of solar radiation by the cloud. The precise nature of aerosol/cloud interactions and how they interact with the water cycle remains a major uncertainty in our understanding of climate processes. Because man-made aerosols are mostly introduced near the Earth's surface, they can be washed out of the atmosphere by rain. They therefore typically remain in the atmosphere for only a few days, and they tend to be concentrated near their sources such as industrial regions. Therefore, they affect climate with a very strong regional pattern and usually produce cooling.

In contrast, greenhouse gases such as carbon dioxide and methane are not washed out, so they have lifetimes of decades or longer. As a result, with continued emissions, they build up in amounts over time, as has been observed. Greenhouse gas concentrations in the atmosphere have increased markedly as a result of human activities since 1750, and they are now higher than at any time in at least the last 650,000 years. It took at least 10,000 years from the end of the last ice age for levels of carbon dioxide to increase 100 parts per million (ppm) by volume to 280 ppm, but that same increase has occurred over only the past 150 years to current values near 380 ppm. About half of that increase has occurred over the last 35 years, owing mainly to combustion of fossil fuels and changes in land use, and the carbon dioxide concentration growth-rate was larger during the last decade than it has been since the beginning of continuous direct measurements in the late 1950s. In the absence of controls, future projections are that the rate of increase in carbon dioxide amount may accelerate, and concentrations could double from pre-industrial values within the next 50 to 100 years. Similarly, owing predominantly to agriculture and fossil fuel use, the global atmospheric concentration of methane has increased from a pre-industrial value of 715 part per billion (ppb) by volume to 1774 ppb in 2005, although growth rates have declined since the early 1990s, consistent with total emissions (sum of natural and anthropogenic sources) being nearly constant over this period. Global nitrous oxide concentrations have increased significantly from pre-industrial values as well.

Together, the combined radiative forcing[2] from these three greenhouse gases is +2.3 Watts per square meter (W m^{-2}), relative to 1750, which dominates the total net anthropogenic forcing (+1.6 W m^{-2}). The total net anthropogenic forcing includes contributions from aerosols (a negative forcing) and several other sources, such as tropospheric ozone and halocarbons.

Climate model simulations that account for such changes in forcings have now reliably shown that global surface warming of recent decades is a response to the increased concentrations of greenhouse gases and sulfate aerosols in the atmosphere. When the models are run without these forcing changes, the remaining natural forcings and intrinsic natural variability fail to capture the almost linear increase in global surface temperatures over the past 25 years or so. But when the anthropogenic forcings are included, the models simulate the observed global temperature record with impressive fidelity (***Figure 1***). Changes in solar irradiance since 1750 are estimated to have caused a radiative forcing of +0.12 W m^{-2}, mainly in the first part of the 20th Century, and this cannot explain the recent warming. Prior to 1979 when direct observations of the sun from space began, changes in solar irradiance are more uncertain, but it is well established that the sun has not caused warming since 1979. Moreover, the models indicate that volcanic and anthropogenic aerosols have offset some of the additional warming that would have resulted from observed increases in greenhouse gas concentrations alone.

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[2] Radiative forcing is a measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. Positive forcing tends to warm the surface while negative forcing tends to cool it.

A significant advancement since the TAR is that a larger number of simulations available from a broader range of models allows for a more definitive evaluation of the role of various forcings in producing not only changes in global average temperature, but also changes in continental and ocean basin scale temperatures, sea level, and changes in extreme events such as frost days and heat waves. The patterns of warming over each

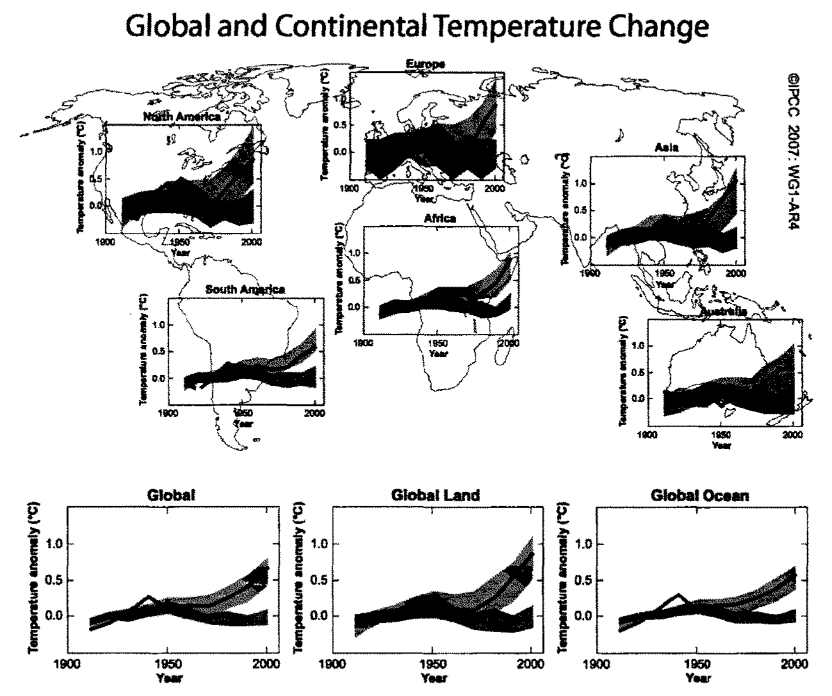


FIGURE 1. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906–2005 (black line) plotted against the center of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5–95% range for 19 simulations from 5 climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5–95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. The figure is taken from the IPCC AR4 WGI Summary for Policymakers (2007).

continent except Antarctica and each ocean basin over the past 50 years, including greater warming over land than over the ocean, and their changes over time, are only simulated by models that include anthropogenic forcing. Attribution studies have also demonstrated that many of the observed changes in indicators of climate extremes consistent with warming, including the annual number of frost days, warm and cold days, and warm and cold nights, have likely occurred as a result of increased anthropogenic forcing. In other words, many of the recently observed changes in climate are now being simulated in models.

The ability of coupled climate models to simulate the temperature evolution on continental scales, and the detection of anthropogenic effects on each continent except Antarctica, provides even stronger evidence of human influence on the global climate than was available to the TAR. No climate model that has used natural forcing only has reproduced either the observed global mean warming trend or the continental mean warming trends. Attribution of temperature change on smaller than continental scales and over time scales of less than 50 years or so has not yet been established mainly because of the much larger natural variability on smaller scales.

Another powerful test of coupled climate models is their ability to simulate climate of the more distant past, such as conditions of the Last Glacial Maximum (order 20,000 years ago) and the relatively warm Mid-Holocene (5,000 years ago). While many aspects of these past climates remain uncertain, key features have been reproduced by climate models using estimated surface conditions and radiative forcing for those periods. A substantial fraction of the reconstructed NH interdecadal temperature variability of the last 500 years, for instance, is very likely attributable to natural external forcing from changes in the sun and effects of volcanic events.

Such results increase our confidence in the observational record and our understanding of how temperature has changed. They also mean that the time histories of the important forcings are reasonably known (for instance, Beryllium isotope measurements can be used to estimate long-term changes in solar output through changes in cosmic radiation) and that the processes being simulated models are adequate enough to make the models very valuable tools.

How will future global temperatures be affected by greenhouse gas emissions from human activity?

The ability of climate models to simulate the past climate record gives us increased confidence in their ability to simulate the future. We can now look back at projections from earlier IPCC assessments and see that the observed rate of global warming since 1990 (about 0.2°C per decade) is within the projected range (0.15°C– 0.30°C per decade). Moreover, the attribution of the recent climate change to increased concentrations of greenhouse gases in the atmosphere has direct implications for the future. Because of the long lifetime of carbon dioxide and the slow equilibration of the oceans, there is a substantial future commitment to further global climate change even in the absence of further emissions of greenhouse gases into the atmosphere. Several of the coupled model experiments performed by modeling groups around the world for the IPCC AR4 explored the concept of climate change commitment. For instance, if concentrations of greenhouse gases were held constant at year 2000 levels (implying a very large reduction in emissions), how much more warming would occur due to the greenhouse gases already in the atmosphere? Such committed climate change is due to: (1) the long lifetime of carbon dioxide and other greenhouse gases; and (2) the long time it takes for warmth to penetrate into the oceans. Under the aforementioned scenario, a further warming trend would occur over the next 20 years a rate of about 0.1°C per decade averaged over the period 2000 to 2020 would occur, with smaller warming rate continuing after that. The associated sea level rise commitment is much longer term, due to the effects of thermal expansion on sea level. Water has the physical property of expanding as it heats up; therefore, as the warming penetrates deeper into the ocean, an ever increasing volume of water expands and contributes to ongoing sea level rise. Since it would take centuries for the entire volume of the ocean to warm in response to the effects of the greenhouse gases we have already put into the air, we are now committed to further sea level rise that would continue for centuries. Further glacial melt is also likely.

The 16 climate modeling groups (from 11 countries, including the U.S.) contributing to the AR4 produced the most extensive internationally coordinated climate change experiment ever performed. In total, 23 global coupled climate models were used to perform simulations of the 20th Century climate (described under the previous question), three scenarios of the 21st Century (based on low, medium and high emission scenarios), and three idealized stabilization experiments. In addition there were idealized carbon dioxide increase experiments, and associated stabilization experiments with doubled and quadrupled carbon dioxide amounts. These data were then collected, archived and made openly available for analysis at the DOE-sponsored Program for Climate Model Diagnosis and Intercomparison (PCMDI) at Lawrence Livermore National Lab (LLNL) in Livermore, CA. Almost 1,000 scientists have accessed these model data, resulting in many papers assessed in the AR4. The outcome of this massive effort is much more extensive analysis, increased certainty of the most robust climate responses across different models, and much better quantification of best estimates and uncertainty ranges of projected warming for different emission scenarios. Moreover, the large model ensemble also provides for better quantification of regional climate change, extremes, climate change commitment, ocean circulation changes, and both near term and longer term climate change in response to future changes in radiative forcing.

Some of the major results include:

- Over the next two decades, all models produce similar warming trends in global surface temperatures, regardless of the scenario. The rate of the projected warming is near 0.2°C per decade, or about twice that of the "commitment" runs.

- Decadal-average warming over each inhabited continent by 2030 is insensitive to the emission scenario; moreover, the temperature change is very likely to exceed the model generated natural temperature variability by at least a factor of two.

- By the middle of the 21st Century the choice of scenario becomes more important for the magnitude of surface warming, and by the end of the 21st Century there are clear consequences for which scenario is followed. The best estimate of the global surface temperature change from today to the end of the century is +1.8°C (with a likely range of +1.1°C to +2.9°C) for the low emission scenario (B1, corresponding to a carbon dioxide equivalent concentration of 600 ppm by 2100) and +4.0°C (+2.4°C to +6.4°C) for the highest emission scenario (A1F1, corresponding to 1,550 ppm).

- Geographical patterns of warming show greatest temperature increases at high northern latitudes and over land, with less warming over the southern oceans and North Atlantic, as has been observed in recent decades. In spite of a slowdown of the meridional overturning circulation and changes in the Gulf Stream in the ocean across models, there is still warming over the North Atlantic and Europe due to the overwhelming effects of the increased concentrations of greenhouse gases.
- Snow cover is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions.
- Sea ice coverage is projected to shrink in polar regions. In some projections, Arctic late-summer sea disappears almost entirely by the latter part of the 21st Century.
- It is very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent.
- Projections of sea level rise by the end of the century are similar to previous estimates, ranging from 30 to 40 cm, but do not include possible ice sheet collapse.
- About 60-70% of the projected sea level rise is due to thermal expansion of sea water. There is less certainty of the future contributions from other sources. For instance, the projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed over the past decade, but how these flow rates might change in the future is not known.
- Increases in the amount of precipitation are very likely in high-latitudes, while decreases are likely in most subtropical land regions, continuing patterns observed in recent trends.

The climate models assessed in the AR4 have better and more complete representations of many physical processes. But as our knowledge of the different components of the climate system and their interactions increases, so does the complexity of climate models. Historical changes in land use and changes in the distribution of continental water due to dams and irrigation, for instance, need to be considered. Future projected land cover changes due to human land uses are also likely to significantly affect climate, especially locally, and these effects are only just now being included in climate models.

One of the major advances in climate modeling in recent years has been the introduction of coupled climate-carbon models. Climate change is expected to influence the capacities of the land and oceans to act as repositories for anthropogenic carbon dioxide, and hence provide a feedback to climate change. These models now allow us to assess the nature of this feedback. Though only relatively few global coupled climate models include the complex processes involved with modeling the carbon cycle, this feedback is positive (adding to more warming) in all models so far considered. Therefore, the addition of carbon cycle feedbacks increases the fraction of anthropogenic emissions that remain in the atmosphere, thereby giving higher values on the warm end of the uncertainty ranges.

Conclusions

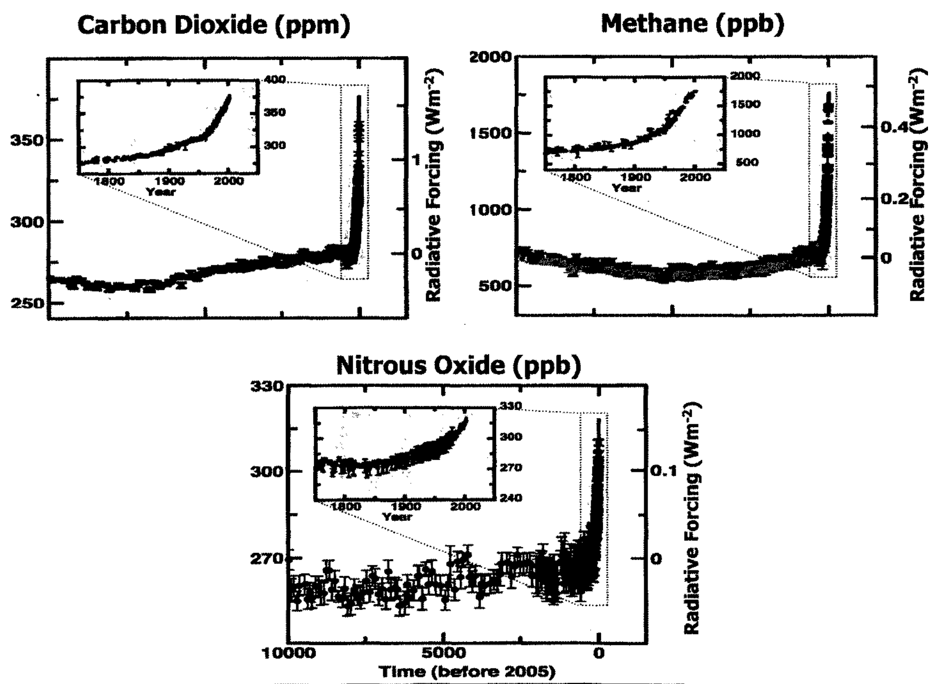
The scientific understanding of climate change is now sufficiently clear to show that climate change from global warming is already upon us. Uncertainties remain, especially regarding how climate will change at regional and local scales. But the climate is changing and the uncertainties make the need for action all the more imperative.

Mitigation actions taken now mainly have benefits 50 years and beyond now. This also means that we will have to adapt to climate change by planning for it and making better predictions of likely outcomes on several time horizons. Action taken now to reduce significantly the build-up of greenhouse gases in the atmosphere will lessen the magnitude and rate of climate change. While some changes arising from global warming are benign or even beneficial, the rate of change as projected exceeds anything seen in nature in the past 10,000 years. It is apt to be disruptive in many ways. Hence it is also vital to plan to cope with the changes, such as enhanced droughts, heat waves and wild fires, and stronger downpours and risk of flooding. Managing water resources will be major challenge in the future.

Again, it is an honor to have the opportunity to address the Subcommittee concerning the science of global climate change. I look forward to answering any questions.

Summary for Policymakers (IPCC AR4)

Changes in Greenhouse Gases



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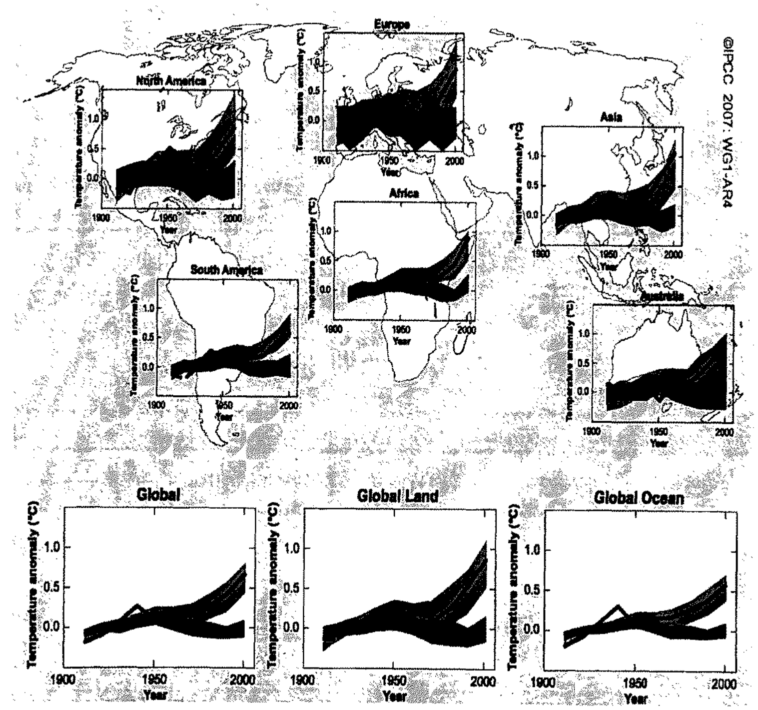
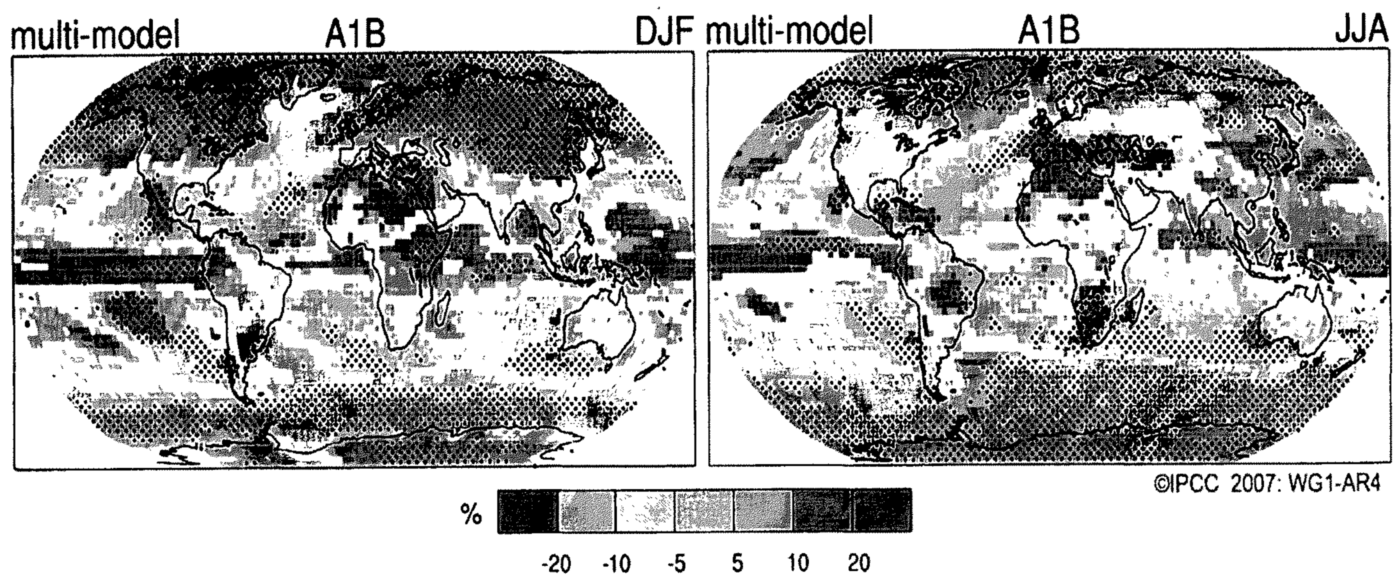
Summary for Policymakers (IPCC AR4)

Global and Continental Temperature Change



Summary for Policymakers (IPCC AR4)

Projected Patterns of Precipitation Change



INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

Climate Change 2007: The Physical Science Basis

Summary for Policymakers

Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

This Summary for Policymakers was formally approved at the 10th Session of Working Group I of the IPCC, Paris, February 2007.

Note:
Text, tables and figures given here are final but subject to copy-editing.

Corrections made as of February 5th, 2007

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Introduction

The Working Group I contribution to the IPCC Fourth Assessment Report describes progress in understanding of the human and natural drivers of climate change[1], observed climate change, climate processes and attribution, and estimates of projected future climate change. It builds upon past IPCC assessments and incorporates new findings from the past six years of research. Scientific progress since the TAR is based upon large amounts of new and more comprehensive data, more sophisticated analyses of data, improvements in understanding of processes and their simulation in models, and more extensive exploration of uncertainty ranges.

The basis for substantive paragraphs in this Summary for Policymakers can be found in the chapter sections specified in curly brackets.

Human and Natural Drivers of Climate Change

Changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties alter the energy balance of the climate system. These changes are expressed in terms of radiative forcing[2], which is used to compare how a range of human and natural factors drive warming or cooling influences on global climate. Since the Third Assessment Report (TAR), new observations and related modelling of greenhouse gases, solar activity, land surface properties and some aspects of aerosols have led to improvements in the quantitative estimates of radiative forcing.

Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years (see Figure SPM-1). The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture. {2.3, 6.4, 7.3}

- Carbon dioxide is the most important anthropogenic greenhouse gas (see Figure SPM-2). The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm[3] in 2005. The atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650,000 years (180 to 300 ppm) as determined from ice cores. The annual carbon dioxide concentration growth-rate was larger during the last 10 years (1995 – 2005 average: 1.9 ppm per year), than it has been since the beginning of continuous direct atmospheric measurements (1960 – 2005 average: 1.4 ppm per year) although there is year-to-year variability in growth rates. {2.3, 7.3}
- The primary source of the increased atmospheric concentration of carbon dioxide since the pre-industrial period results from fossil fuel use, with land use change providing another significant but smaller contribution. Annual fossil carbon dioxide emissions[4] increased from an average of 6.4 [6.0 to 6.8] [5] GtC

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[1] *Climate change* in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

[2] *Radiative forcing* is a measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. Positive forcing tends to warm the surface while negative forcing tends to cool it. In this report radiative forcing values are for 2005 relative to pre-industrial conditions defined at 1750 and are expressed in watts per square metre ($W\ m^{-2}$). See Glossary and Section 2.2 for further details.

[3] ppm (parts per million) or ppb (parts per billion, 1 billion = 1,000 million) is the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air. For example: 300 ppm means 300 molecules of a greenhouse gas per million molecules of dry air.

[4] Fossil carbon dioxide emissions include those from the production, distribution and consumption of fossil fuels and as a by-product from cement production. An emission of 1 GtC corresponds to 3.67 $GtCO_2$.

[5] In general, uncertainty ranges for results given in this Summary for Policymakers are 90% uncertainty intervals unless stated otherwise, i.e., there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range. Best estimates are given where available. Assessed uncertainty intervals are not always symmetric about the corresponding best estimate. Note that a number of uncertainty ranges in the Working Group I TAR corresponded to 2-sigma (95%), often using expert judgement.

(23.5 [22.0 to 25.0] $GtCO_2$) per year in the 1990s, to 7.2 [6.9 to 7.5] GtC (26.4 [25.3 to 27.5] $GtCO_2$) per year in 2000–2005 (2004 and 2005 data are interim estimates). Carbon dioxide emissions associated with land-use change are estimated to be 1.6 [0.5 to 2.7] GtC (5.9 [1.8 to 9.9] $GtCO_2$) per year over the 1990s, although these estimates have a large uncertainty. {7.3}

Changes in Greenhouse Gases from Ice-Core and Modern Data

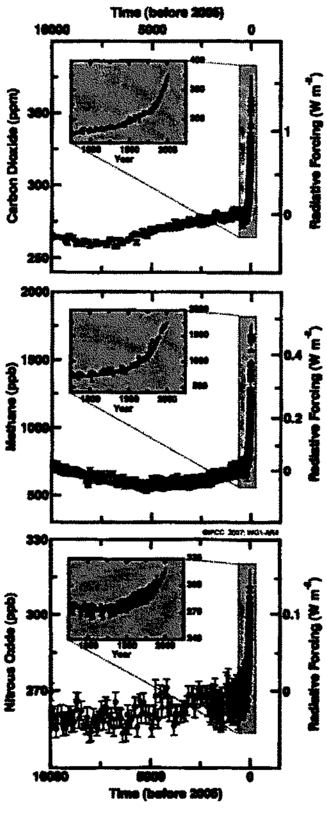

FIGURE SPM-1. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels. {Figure 6.4}

- The global atmospheric concentration of methane has increased from a pre-industrial value of about 715 ppb to 1732 ppb in the early 1990s, and is 1774 ppb in 2005. The atmospheric concentration of methane in 2005 exceeds by far the natural range of the last 650,000 years (320 to 790 ppb) as determined from ice cores. Growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. It is *very likely*[6] that the observed increase in methane concentration is due to anthropogenic activities, predominantly agriculture and fossil fuel use, but relative contributions from different source types are not well determined. {2.3, 7.4}
- The global atmospheric nitrous oxide concentration increased from a pre-industrial value of about 270 ppb to 319 ppb in 2005. The growth rate has been approximately constant since 1980. More than a third of all nitrous oxide emissions are anthropogenic and are primarily due to agriculture. {2.3, 7.4}

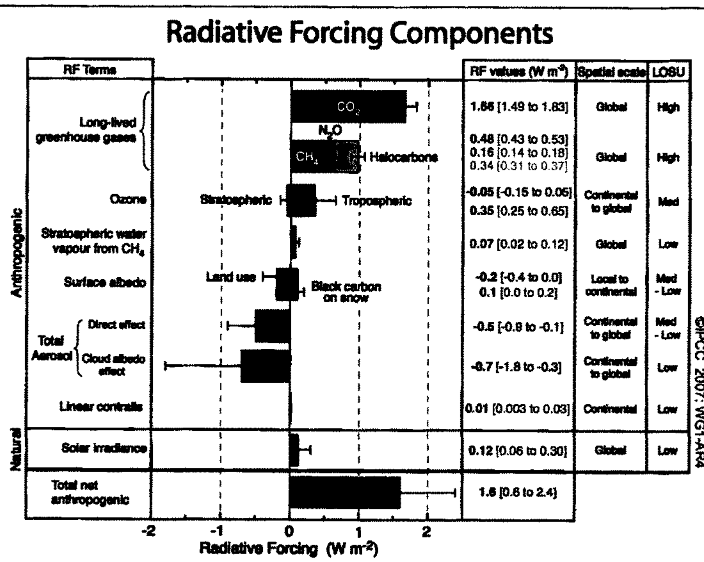

FIGURE SPM-2. Global-average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. Range for linear contrails does not include other possible effects of aviation on cloudiness. {2.9, Figure 2.20}

[6] In this Summary for Policymakers, the following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: *Virtually certain* > 99% probability of occurrence, *Extremely likely* > 95%, *Very likely* > 90%, *Likely* > 66%, *More likely than not* > 50%, *Unlikely* < 33%, *Very unlikely* < 10%, *Extremely unlikely* < 5%. (See Box TS.1.1 for more details).

The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (TAR), leading to *very high confidence*[7] that the globally averaged net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W m^{-2}. (see Figure SPM-2). {2.3. 6.5, 2.9}

- The combined radiative forcing due to increases in carbon dioxide, methane, and nitrous oxide is +2.30 [+2.07 to +2.53] W m^{-2}, and its rate of increase during the industrial era is *very likely* to have been unprecedented in more than 10,000 years (see Figures SPM-1 and SPM-2). The carbon dioxide radiative forcing increased by 20% from 1995 to 2005, the largest change for any decade in at least the last 200 years. {2.3, 6.4}
- Anthropogenic contributions to aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect, with a total direct radiative forcing of -0.5 [-0.9 to -0.1] W m^{-2} and an indirect cloud albedo forcing of -0.7 [-1.8 to -0.3] W m^{-2}. These forcings are now better understood than at the time of the TAR due to improved *in situ*, satellite and ground-based measurements and more comprehensive modelling, but remain the dominant uncertainty in radiative forcing. Aerosols also influence cloud lifetime and precipitation. {2.4, 2.9, 7.5}
- Significant anthropogenic contributions to radiative forcing come from several other sources. Tropospheric ozone changes due to emissions of ozone-forming chemicals (nitrogen oxides, carbon monoxide, and hydrocarbons) contribute +0.35 [+0.25 to +0.65] W m^{-2}. The direct radiative forcing due to changes in halocarbons[8] is +0.34 [+0.31 to +0.37] W m^{-2}. Changes in surface albedo, due to land-cover changes and deposition of black carbon aerosols on snow, exert respective forcings of -0.2 [-0.4 to 0.0] and +0.1 [0.0 to +0.2] W m^{-2}. Additional terms smaller than ±0.1 W m^{-2} are shown in Figure SPM-2. {2.3, 2.5, 7.2}
- Changes in solar irradiance since 1750 are estimated to cause a radiative forcing of +0.12 [+0.06 to +0.30] W m^{-2}, which is less than half the estimate given in the TAR. {2.7}

DIRECT OBSERVATIONS OF RECENT CLIMATE CHANGE

Since the TAR, progress in understanding how climate is changing in space and in time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. Increasingly comprehensive observations are available for glaciers and snow cover since the 1960s, and for sea level and ice sheets since about the past decade. However, data coverage remains limited in some regions.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (see Figure SPM-3). {3.2, 4.2, 5.5}

- Eleven of the last twelve years (1995 -2006) rank among the 12 warmest years in the instrumental record of global surface temperature[9] (since 1850). The updated 100-year linear trend (1906–2005) of 0.74 [0.56 to 0.92]°C is therefore larger than the corresponding trend for 1901-2000 given in the TAR of 0.6 [0.4 to 0.8]°C. The linear warming trend over the last 50 years (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the last 100 years. The total temperature increase from 1850 – 1899 to 2001 – 2005 is 0.76 [0.57 to 0.95]°C. Urban heat island effects are real but local, and have a negligible influence (less than 0.006°C per decade over land and zero over the oceans) on these values. {3.2}

[7] In this Summary for Policymakers the following levels of confidence have been used to express expert judgments on the correctness of the underlying science: *very high confidence* at least a 9 out of 10 chance of being correct; *high confidence* about an 8 out of 10 chance of being correct. (See Box TS.1.1)

[8] Halocarbon radiative forcing has been recently assessed in detail in IPCC's Special Report on Safeguarding the Ozone Layer and the Global Climate System (2005).

[9] The average of near surface air temperature over land, and sea surface temperature.

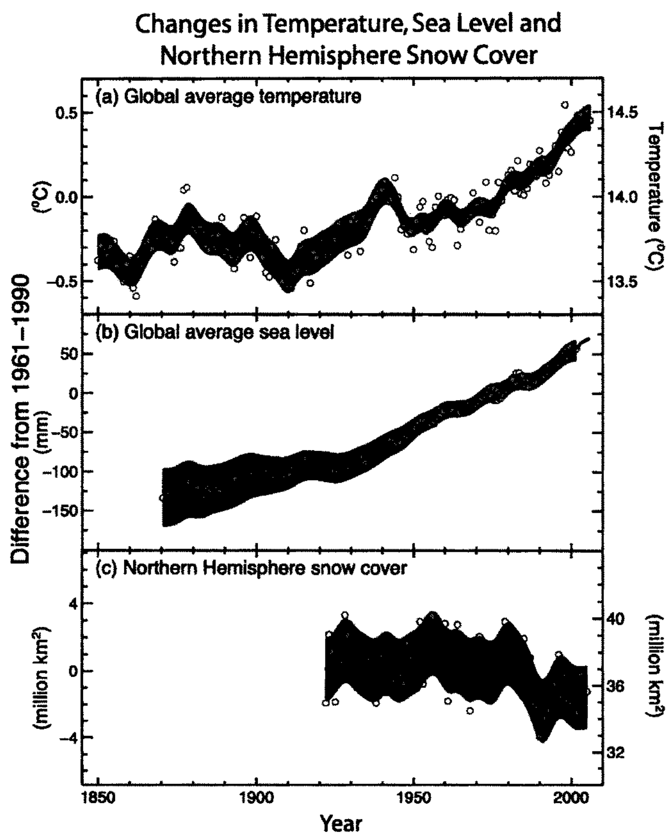

FIGURE SPM-3. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {FAQ 3.1, Figure 1, Figure 4.2 and Figure 5.13}

- New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to those of the surface temperature record and are consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR. {3.2, 3.4}

- The average atmospheric water vapour content has increased since at least the 1980s over land and ocean as well as in the upper troposphere. The increase is broadly consistent with the extra water vapour that warmer air can hold. {3.4}
- Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been absorbing more than 80% of the heat added to the climate system. Such warming causes seawater to expand, contributing to sea level rise (see Table SPM-1). {5.2, 5.5}

Table SPM-1. Observed rate of sea level rise and estimated contributions from different sources. {5.5, Table 5.3}

	Rate of sea level rise (mm per year)	
Source of sea level rise	**1961 – 2003**	**1993 – 2003**
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and ice caps	0.50 ± 0.18	0.77 ± 0.22
Greenland ice sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheet	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	2.8 ± 0.7
Observed total sea level rise	1.8 ± 0.5[a]	3.1 ± 0.7[a]
Difference (Observed minus sum of estimated climate contributions)	0.7 ± 0.7	0.3 ± 1.0

Table note:
[a] Data prior to 1993 are from tide gauges and after 1993 are from satellite altimetry.

- Mountain glaciers and snow cover have declined on average in both hemispheres. Widespread decreases in glaciers and ice caps have contributed to sea level rise (ice caps do not include contributions from the Greenland and Antarctic ice sheets). (See Table SPM-1.) {4.6, 4.7, 4.8, 5.5}
- New data since the TAR now show that losses from the ice sheets of Greenland and Antarctica have *very likely* contributed to sea level rise over 1993 to 2003 (see Table SPM-1). Flow speed has increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior of the ice sheets. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues. Such dynamical ice loss is sufficient to explain most of the Antarctic net mass loss and approximately half of the Greenland net mass loss. The remainder of the ice loss from Greenland has occurred because losses due to melting have exceeded accumulation due to snowfall. {4.6, 4.8, 5.5}
- Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The rate was faster over 1993 to 2003, about 3.1 [2.4 to 3.8] mm per year. Whether the faster rate for 1993 to 2003 reflects decadal variability or an increase in the longer-term trend is unclear. There is *high confidence* that the rate of observed sea level rise increased from the 19th to the 20th century. The total 20th century rise is estimated to be 0.17 [0.12 to 0.22] m. {5.5}
- For 1993-2003, the sum of the climate contributions is consistent within uncertainties with the total sea level rise that is directly observed (see Table SPM-1). These estimates are based on improved satellite and *in-situ* data now available. For the period of 1961 to 2003, the sum of climate contributions is estimated to be smaller than the observed sea level rise. The TAR reported a similar discrepancy for 1910 to 1990. {5.5}

At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones[10]. {3.2, 3.3, 3.4, 3.5, 3.6, 5.2}

- Average Arctic temperatures increased at almost twice the global average rate in the past 100 years. Arctic temperatures have high decadal variability, and a warm period was also observed from 1925 to 1945. {3.2}
- Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. These values are consistent with those reported in the TAR. {4.4}
- Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic (by up to 3°C). The maximum area covered by seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with a decrease in spring of up to 15%. {4.7}
- Long-term trends from 1900 to 2005 have been observed in precipitation amount over many large regions[11]. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Precipitation is highly variable spatially and temporally, and data are limited in some regions. Long-term trends have not been observed for the other large regions assessed[11]. {3.3, 3.9}
- Changes in precipitation and evaporation over the oceans are suggested by freshening of mid and high latitude waters together with increased salinity in low latitude waters. {5.2}
- Mid-latitude westerly winds have strengthened in both hemispheres since the 1960s. {3.5}
- More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Increased drying linked with higher temperatures and decreased precipitation have contributed to changes in drought. Changes in sea surface temperatures (SST), wind patterns, and decreased snowpack and snow cover have also been linked to droughts. {3.3}
- The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour. {3.8, 3.9}
- Widespread changes in extreme temperatures have been observed over the last 50 years. Cold days, cold nights and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent (see Table SPM-2). {3.8}
- There is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures. There are also suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. There is no clear trend in the annual numbers of tropical cyclones. {3.8}

[10] Tropical cyclones include hurricanes and typhoons.

[11] The assessed regions are those considered in the regional projections Chapter of the TAR and in Chapter 11 of this Report.

Table SPM-2. Recent trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late 20th century trend. {Tables 3.7, 3.8, 9.4, Sections 3.8, 5.5, 9.7, 11.2-11.9}

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend [b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely* [c]	*Likely* [d]	*Virtually certain* [d]
Warmer and more frequent hot days and nights over most land areas	*Very likely* [e]	*Likely (nights)* [d]	*Virtually certain* [d]
Warm spells / heat waves. Frequency increases over most land areas	*Likely*	*More likely than not* [f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not* [f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not* [f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis) [g]	*Likely*	*More likely than not* [f, h]	*Likely* [i]

Table notes:

[a] See Table 3.7 for further details regarding definitions.

[b] See Table TS-4, Box TS.3.4 and Table 9.4.

[c] Decreased frequency of cold days and nights (coldest 10%).

[d] Warming of the most extreme days and nights each year.

[e] Increased frequency of hot days and nights (hottest 10%).

[f] Magnitude of anthropogenic contributions not assessed. Attribution for these phenomena based on expert judgement rather than formal attribution studies.

[g] Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

[h] Changes in observed extreme high sea level closely follow the changes in average sea level {5.5.2.6}. It is *very likely* that anthropogenic activity contributed to a rise in average sea level. {9.5.2}

[i] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period {10.6}. The effect of changes in regional weather systems on sea level extremes has not been assessed.

Some aspects of climate have not been observed to change. {3.2, 3.8, 4.4, 5.3}

- A decrease in diurnal temperature range (DTR) was reported in the TAR, but the data available then extended only from 1950 to 1993. Updated observations reveal that DTR has not changed from 1979 to 2004 as both day- and night-time temperature have risen at about the same rate. The trends are highly variable from one region to another. {3.2}
- Antarctic sea ice extent continues to show inter-annual variability and localized changes but no statistically significant average trends, consistent with the lack of warming reflected in atmospheric temperatures averaged across the region. {3.2, 4.4}

- There is insufficient evidence to determine whether trends exist in the meridional overturning circulation of the global ocean or in small scale phenomena such as tornadoes, hail, lightning and dust-storms. {3.8, 5.3}

A PALEOCLIMATIC PERSPECTIVE

Paleoclimatic studies use changes in climatically sensitive indicators to infer past changes in global climate on time scales ranging from decades to millions of years. Such proxy data (e.g., tree ring width) may be influenced by both local temperature and other factors such as precipitation, and are often representative of particular seasons rather than full years. Studies since the TAR draw increased confidence from additional data showing coherent behaviour across multiple indicators in different parts of the world. However, uncertainties generally increase with time into the past due to increasingly limited spatial coverage.

Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years. The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise. {6.4, 6.6}

- Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. Some recent studies indicate greater variability in Northern Hemisphere temperatures than suggested in the TAR, particularly finding that cooler periods existed in the 12 to 14th, 17th, and 19th centuries. Warmer periods prior to the 20th century are within the uncertainty range given in the TAR. {6.6}
- Global average sea level in the last interglacial period (about 125,000 years ago) was *likely* 4 to 6 m higher than during the 20th century, mainly due to the retreat of polar ice. Ice core data indicate that average polar temperatures at that time were 3 to 5°C higher than present, because of differences in the Earth's orbit. The Greenland ice sheet and other Arctic ice fields *likely* contributed no more than 4 m of the observed sea level rise. There may also have been a contribution from Antarctica. {6.4}

UNDERSTANDING AND ATTRIBUTING CLIMATE CHANGE

This Assessment considers longer and improved records, an expanded range of observations, and improvements in the simulation of many aspects of climate and its variability based on studies since the TAR. It also considers the results of new attribution studies that have evaluated whether observed changes are quantitatively consistent with the expected response to external forcings and inconsistent with alternative physically plausible explanations.

Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations[12]. This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in greenhouse gas concentrations". Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns (see Figure SPM-4 and Table SPM-2). {9.4, 9.5}

- It is *likely* that increases in greenhouse gas concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place. {2.9, 7.5, 9.4}
- The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is *extremely unlikely* that global climate change of the past fifty years can be explained without external forcing, and *very likely* that it is not due to known natural causes alone. {4.8, 5.2, 9.4, 9.5, 9.7}

[12] Consideration of remaining uncertainty is based on current methodologies.

- Warming of the climate system has been detected in changes of surface and atmospheric temperatures, temperatures in the upper several hundred metres of the ocean and in contributions to sea level rise. Attribution studies have established anthropogenic contributions to all of these changes. The observed pattern of tropospheric warming and stratospheric cooling is *very likely* due to the combined influences of greenhouse gas increases and stratospheric ozone depletion. {3.2, 3.4, 9.4, 9.5}

- It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica (see Figure SPM-4). The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are only simulated by models that include anthropogenic forcing. The ability of coupled climate models to simulate the observed temperature evolution on each of six continents provides stronger evidence of human influence on climate than was available in the TAR. {3.2, 9.4}

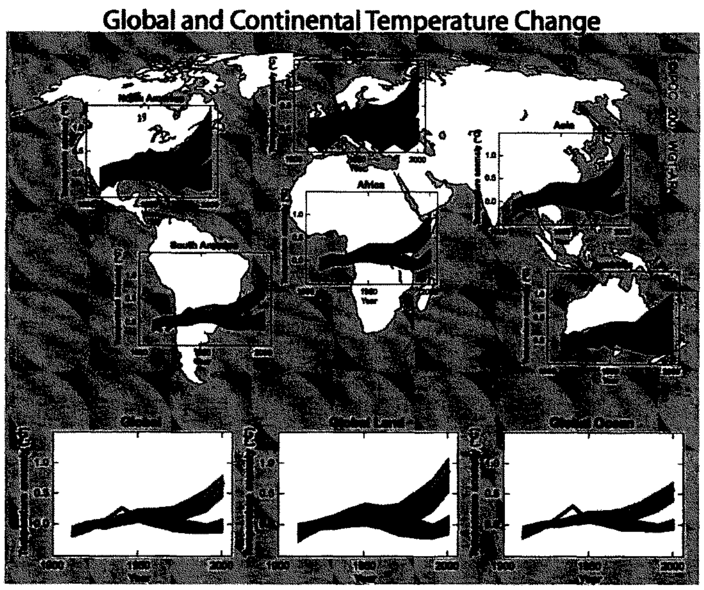

FIGURE SPM-4. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906–2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5–95% range for 19 simulations from 5 climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5–95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. {FAQ 9.2, Figure 1}

- Difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales. On these scales, natural climate variability is relatively larger making it harder to distinguish changes expected due to external forcings. Uncertainties in local forcings and feedbacks also make it difficult to estimate the contribution of greenhouse gas increases to observed small-scale temperature changes. {8.3, 9.4}
- Anthropogenic forcing is *likely* to have contributed to changes in wind patterns[13], affecting extra-tropical storm tracks and temperature patterns in both hemispheres. However, the observed changes in the Northern Hemisphere circulation are larger than simulated in response to 20th century forcing change. {3.5, 3.6, 9.5, 10.3}
- Temperatures of the most extreme hot nights, cold nights and cold days are *likely* to have increased due to anthropogenic forcing. It is *more likely than not* that anthropogenic forcing has increased the risk of heat waves (see Table SPM-2). {9.4}

Analysis of climate models together with constraints from observations enables an assessed *likely* range to be given for climate sensitivity for the first time and provides increased confidence in the understanding of the climate system response to radiative forcing. {6.6, 8.6, 9.6, Box 10.2}

- The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations. It is *likely* to be in the range 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values. Water vapour changes represent the largest feedback affecting climate sensitivity and are now better understood than in the TAR. Cloud feedbacks remain the largest source of uncertainty. {8.6, 9.6, Box 10.2}
- It is *very unlikely* that climate changes of at least the seven centuries prior to 1950 were due to variability generated within the climate system alone. A significant fraction of the reconstructed Northern Hemisphere interdecadal temperature variability over those centuries is *very likely* attributable to volcanic eruptions and changes in solar irradiance, and it is *likely* that anthropogenic forcing contributed to the early 20th century warming evident in these records. {2.7, 2.8, 6.6, 9.3}

PROJECTIONS OF FUTURE CHANGES IN CLIMATE

A major advance of this assessment of climate change projections compared with the TAR is the large number of simulations available from a broader range of models. Taken together with additional information from observations, these provide a quantitative basis for estimating likelihoods for many aspects of future climate change. Model simulations cover a range of possible futures including idealised emission or concentration assumptions. These include SRES[14] illustrative marker scenarios for the 2000–2100 period and model experiments with greenhouse gases and aerosol concentrations held constant after year 2000 or 2100.

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. {10.3, 10.7}

[13] In particular, the Southern and Northern Annular Modes and related changes in the North Atlantic Oscillation. {3.6, 9.5, Box TS.3.1}

[14] SRES refers to the IPCC Special Report on Emission Scenarios (2000). The SRES scenario families and illustrative cases, which did not include additional climate initiatives, are summarized in a box at the end of this Summary for Policymakers. Approximate CO_2 equivalent concentrations corresponding to the computed radiative forcing due to anthropogenic greenhouse gases and aerosols in 2100 (see p. 823 of the TAR) for the SRES B1, A1T, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550 ppm respectively. Scenarios B1, A1B, and A2 have been the focus of model inter-comparison studies and many of those results are assessed in this report.

- Since IPCC's first report in 1990, assessed projections have suggested global averaged temperature increases between about 0.15 and 0.3°C per decade for 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections. {1.2, 3.2}
- Model experiments show that even if all radiative forcing agents are held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1°C per decade, due mainly to the slow response of the oceans. About twice as much warming (0.2°C per decade) would be expected if emissions are within the range of the SRES scenarios. Best-estimate projections from models indicate that decadal-average warming over each inhabited continent by 2030 is insensitive to the choice among SRES scenarios and is *very likely* to be at least twice as large as the corresponding model-estimated natural variability during the 20th century. {9.4, 10.3, 10.5, 11.2–11.7, Figure TS-29}

Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. {10.3}

- Advances in climate change modelling now enable best estimates and *likely* assessed uncertainty ranges to be given for projected warming for different emission scenarios. Results for different emission scenarios are provided explicitly in this report to avoid loss of this policy-relevant information. Projected globally-averaged surface warmings for the end of the 21st century (2090–2099) relative to 1980–1999 are shown in Table SPM-3. These illustrate the differences between lower to higher SRES emission scenarios and the projected warming uncertainty associated with these scenarios. {10.5}
- Best estimates and *likely* ranges for globally average surface air warming for six SRES emissions marker scenarios are given in this assessment and are shown in Table SPM-3. For example, the best estimate for the low scenario (B1) is 1.8°C (*likely* range is 1.1°C to 2.9°C), and the best estimate for the high scenario (A1FI) is 4.0°C (*likely* range is 2.4°C to 6.4°C). Although these projections are broadly consistent with the span quoted in the TAR (1.4 to 5.8°C), they are not directly comparable (see Figure SPM-5). The AR4 is more advanced as it provides best estimates and an assessed likelihood range for each of the marker scenarios. The new assessment of the *likely* ranges now relies on a larger number of climate models of increasing complexity and realism, as well as new information regarding the nature of feedbacks from the carbon cycle and constraints on climate response from observations. {10.5}

Table SPM-3. Projected globally averaged surface warming and sea level rise at the end of the 21st century. {10.5, 10.6, Table 10.7}

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Table notes:

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulaion Models (AOGCMs).

[b] Year 2000 constant composition is derived from AOGCMs only.

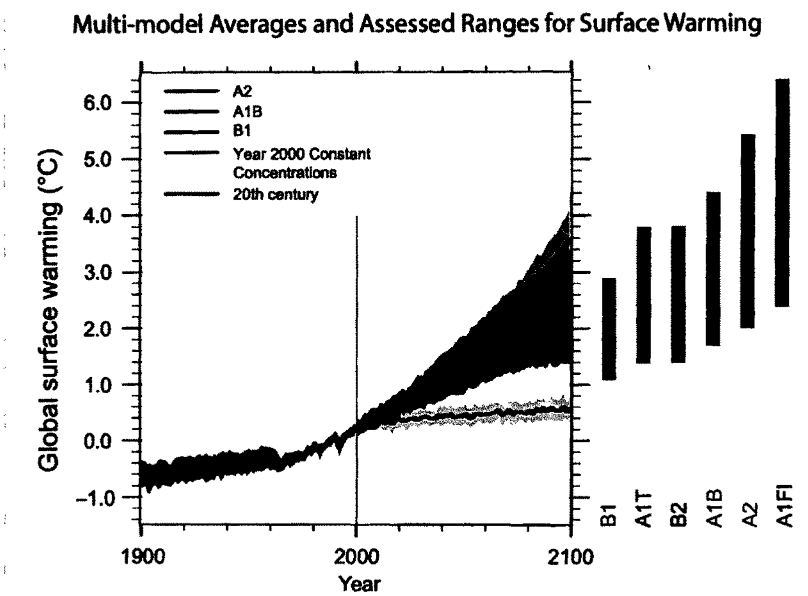

FIGURE SPM-5. Solid lines are multi-model global averages of surface warming (relative to 1980-99) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the plus/minus one standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The gray bars at right indicate the best estimate (solid line within each bar) and the *likely* range assessed for the six SRES marker scenarios. The assessment of the best estimate and *likely* ranges in the gray bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. {Figures 10.4 and 10.29}

- Warming tends to reduce land and ocean uptake of atmospheric carbon dioxide, increasing the fraction of anthropogenic emissions that remains in the atmosphere. For the A2 scenario, for example, the climate-carbon cycle feedback increases the corresponding global average warming at 2100 by more than 1°C. Assessed upper ranges for temperature projections are larger than in the TAR (see Table SPM-3) mainly because the broader range of models now available suggests stronger climate-carbon cycle feedbacks. {7.3, 10.5}

- Model-based projections of global average sea level rise at the end of the 21st century (2090-2099) are shown in Table SPM-3. For each scenario, the midpoint of the range in Table SPM-3 is within 10% of the TAR model average for 2090-2099. The ranges are narrower than in the TAR mainly because of improved information about some uncertainties in the projected contributions[15]. {10.6}

- Models used to date do not include uncertainties in climate-carbon cycle feedback nor do they include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. For example, if this contribution were to grow

[15] TAR projections were made for 2100, whereas projections in this Report are for 2090-2099. The TAR would have had similar ranges to those in Table SPM-2 if it had treated the uncertainties in the same way.

linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios shown in Table SPM-3 would increase by 0.1 m to 0.2 m. Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise. {10.6}

- Increasing atmospheric carbon dioxide concentrations leads to increasing acidification of the ocean. Projections based on SRES scenarios give reductions in average global surface ocean pH[16] of between 0.14 and 0.35 units over the 21st century, adding to the present decrease of 0.1 units since pre-industrial times. {5.4, Box 7.3, 10.4}

There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and of ice. {8.2, 8.3, 8.4, 8.5, 9.4, 9.5, 10.3, 11.1}

- Projected warming in the 21st century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic ocean (see Figure SPM-6). {10.3}

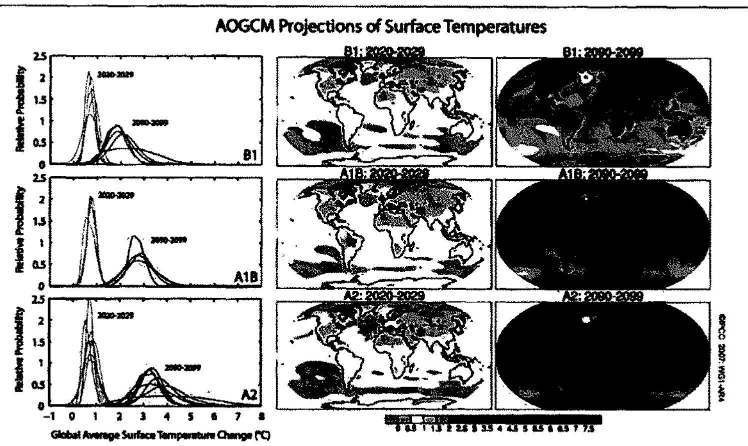

FIGURE SPM-6. Projected surface temperature changes for the early and late 21st century relative to the period 1980–1999. The central and right panels show the Atmosphere-Ocean General Circulation multi-Model average projections for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over decades 2020–2029 (center) and 2090–2099 (right). The left panel shows corresponding uncertainties as the relative probabilities of estimated global average warming from several different AOGCM and EMICs studies for the same periods. Some studies present results only for a subset of the SRES scenarios, or for various model versions. Therefore the difference in the number of curves, shown in the left-hand panels, is due only to differences in the availability of results. {Figures 10.8 and 10.28}

[16] Decreases in pH correspond to increases in acidity of a solution. See Glossary for further details.

- Snow cover is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. {10.3, 10.6}
- Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century. {10.3}
- It is *very likely* that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent. {10.3}
- Based on a range of models, it is *likely* that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical SSTs. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period. {9.5, 10.3, 3.8}
- Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation, and temperature patterns, continuing the broad pattern of observed trends over the last half-century. {3.6, 10.3}
- Since the TAR there is an improving understanding of projected patterns of precipitation. Increases in the amount of precipitation are *very likely* in high-latitudes, while decreases are *likely* in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100, see Figure SPM-7), continuing observed patterns in recent trends. {3.3, 8.3, 9.5, 10.3, 11.2 to 11.9}
- Based on current model simulations, it is *very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century. The multi-model average reduction by 2100 is 25% (range from zero to about 50%) for SRES emission scenario A1B. Temperatures in the Atlantic region are projected to increase despite such changes due to the much larger warming associated with projected increases of greenhouse gases. It is *very unlikely* that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence. {10.3, 10.7}

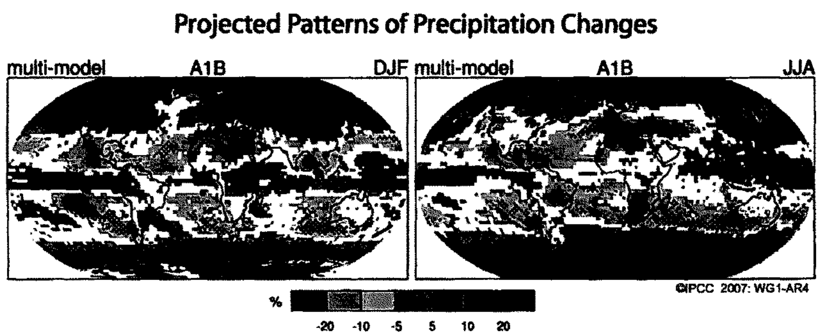

FIGURE SPM-7. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}

Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized. {10.4, 10.5, 10.7}

- Climate carbon cycle coupling is expected to add carbon dioxide to the atmosphere as the climate system warms, but the magnitude of this feedback is uncertain. This increases the uncertainty in the trajectory of carbon dioxide emissions required to achieve a particular stabilisation level of atmospheric carbon dioxide concentration. Based on current understanding of climate carbon cycle feedback, model studies suggest that to stabilise at 450 ppm carbon dioxide, could require that cumulative emissions over the 21st century be reduced from an average of approximately 670 [630 to 710] GtC (2460 [2310 to 2600] $GtCO_2$) to approximately 490 [375 to 600] GtC (1800 [1370 to 2200] $GtCO_2$). Similarly, to stabilise at 1000 ppm this feedback could require that cumulative emissions be reduced from a model average of approximately 1415 [1340 to 1490] GtC (5190 [4910 to 5460] $GtCO_2$) to approximately 1100 [980 to 1250] GtC (4030 [3590 to 4580] $GtCO_2$). {7.3, 10.4}
- If radiative forcing were to be stabilized in 2100 at B1 or A1B levels[11] a further increase in global average temperature of about 0.5°C would still be expected, mostly by 2200. {10.7}
- If radiative forcing were to be stabilized in 2100 at A1B levels[11], thermal expansion alone would lead to 0.3 to 0.8 m of sea level rise by 2300 (relative to 1980–1999). Thermal expansion would continue for many centuries, due to the time required to transport heat into the deep ocean. {10.7}
- Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest ice mass losses increase with temperature more rapidly than gains due to precipitation and that the surface mass balance becomes negative at a global average warming (relative to pre-industrial values) in excess of 1.9 to 4.6°C. If a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m. The corresponding future temperatures in Greenland are comparable to those inferred for the last interglacial period 125,000 years ago, when paleoclimatic information suggests reductions of polar land ice extent and 4 to 6 m of sea level rise. {6.4, 10.7}
- Dynamical processes related to ice flow not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude. {4.6, 10.7}
- Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. {10.7}
- Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the timescales required for removal of this gas from the atmosphere. {7.3, 10.3}

The Emission Scenarios of the IPCC Special Report on Emission Scenarios (SRES)[17]

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

[17] Emission scenarios are not assessed in this Working Group One report of the IPCC. This box summarizing the SRES scenarios is taken from the TAR and has been subject to prior line by line approval by the Panel.